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NanoByg

A survey of nanoinnovation in Danish Construction

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Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Munch-Andersen, M., Molin, M., Koch, C., Bonke, S., Storgaard, K., Rasmussen, T. V., Geiker, M., Ramsgaard Thomsen, M., Gamborg, K., Bøgedal, M., & Paustian, L. (2007). *NanoByg: A survey of nanoinnovation in Danish Construction*. Danmarks Tekniske Universitet, Risø Nationallaboratoriet for Bæredygtig Energi. Risø-Report No. 1602 (EN)

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Bridging nanotechnological opportunities and construction needs

NanoByg

A survey of nanoinnovation in Danish Construction

Risø-R-1602 (EN)



Risø National Laboratory
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Roskilde, Denmark
May 2007



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Title: NanoByg – a survey of nanoinnovation in Danish construction
Department: Systems Analysis Department

Risø-R-1602 (EN)
May 2007

ISSN 0106-2840
ISBN 978-87-550-3589-8

Contract no.:

Group's own reg. no.:
1220088

Sponsorship:
Realdania

Cover :
Storebæltsbroen
Picture taken by Boback

<http://www.flickr.com/photos/boback/266497577/>

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Preface

NanoByg is a pre-project funded by the private strategic foundation Realdania running in the period November 2006 until March 2007. The pre-project looks into the perspectives and potentials of nanotechnology in Danish construction. The purpose is to establish a basis for discussion on a potential initiative within nanoconstruction (termed NanoByg), with RealDania as well as various ministries and other funding agents.. The pre-project also seeks to establish knowledge of and links between the nano science community and the construction industry to facilitate future cooperation between these areas.

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1 Introduction



*Lundgaard & Tranberg.
Industrikollegiet, 2004,
København.
Photographer: Michael Beck,
Lundgaard & Tranberg.*



*Lundgaard & Tranberg
Industrikollegiet, 2004,
København.
Photographer: Michael Beck,
Lundgaard & Tranberg.*

Nanotechnology is about the manipulation of matter at the nanoscale. Few technologies have created so much hype and attracted so much funding globally as nanotechnology has over the last 5–10 years. There is a global race to take the lead in what many expect to be the next industrial revolution (Luther, 2004, Lux Research 2004, Hullmann, 2006). Like ICT and biotechnology, nanotechnology is a general purpose technology that is expected to have pervasive effects on the economy. Just how strong the impact will be and where it will affect industry and society most, it is still very difficult to say. The visions and hype are considerable, but the technology is still at an early stage of development and commercialisation has only just begun.

The construction sector was among the first to be identified as a promising application area for nanotechnology back in the beginning of the 1990s (Bartos et al., 2004, Gann, 2003). But today we see that the construction industry is falling behind other sectors in applying nanotechnology (Bartos et al., 2004). This report looks into the potential of nanotechnology in the construction industry and in particular discusses the possibility of a Danish initiative – called NanoByg – in this area.

The core challenge that a possible NanoByg initiative must address can be formulated like this:

How do we create innovation in the intersection between the needs of the construction sector and the emerging nanotechnological opportunities?

Behind the idea of NanoByg lie three assumptions:

1. The enabling character of nanotechnology means that it has the potential to create radical and systemic innovation within architecture and construction.
2. Present (Danish) nanoscience is to a large extent oriented at applications in other industries than construction – so it is currently unlikely to have a significant impact on the construction industry.
3. The fragmented nature of the construction sector means that it is likely to have a low uptake, spread and development of such a new and advanced technology as nanotechnology unless careful action is taken.

In this report we will discuss these assumptions further. Key elements are a short analysis of the innovation trends and dynamics of respectively construction and nanotechnology, and a mapping of the activities and actors that are or could



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Industrikollegiet, 2004,
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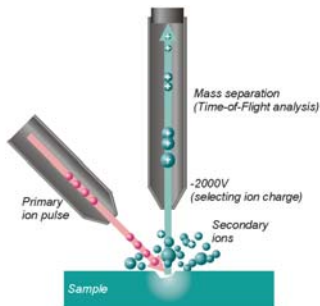
become relevant for the application of nanotechnology in architecture and construction. The focus here is very much on identifying *potential* nano-activities of relevance for construction and not just existing activities, which, as our mapping shows, are quite limited.

If the three assumptions hold true, there are important barriers to the potential that nano-construction holds, both on the construction side and the nanotechnology side. These barriers would be addressed by a possible NanoByg initiative both analytically and practically. So the starting point of the NanoByg idea is that there is a need for an initiative which goes beyond traditional research projects and actively seeks to strengthen the collaboration and knowledge brokering between the construction sector (material and component manufacturers, contractors, architects, consultancy, clients and clients representative) and the nanotech community (Universities, GTS, and nano-dedicated companies). NanoByg should seek to address the entire chain from idea generation to value creation on the market, a point we will return to in Chapter 6. The focus of NanoByg is therefore on both research and innovation, or rather how to create “a fast lane” from research to innovation.

1.1 What is nanotechnology and what could it mean for construction?

Nanotechnology is based on the exploitation of the new properties which are attained by structuring materials and surfaces in length scales of 1 to 100 nm. The lower boundary corresponds to the size of single molecules, which is the length scale used in chemistry, while the upper boundary corresponds to a level of detail just below what is visible with an optical microscope. The special thing about the nanoscale is, that it is typical for the “thickness” of the interface between two materials. This means that the properties of materials structured at the nanoscale are dominated by the interface properties rather than the classical chemical properties of matter.

In the field of construction materials, this is particularly interesting for concrete and composite materials. Here nanotechnology will play an important role in the development of the next generation of high-performance materials. By optimising the interface between fibre and matrix, you can achieve mechanical properties comparable to steel; by adding nanoparticles to concrete, it is possible to achieve a much denser material, which is stronger and less susceptible to degradation than normal concrete, a concept that Densit® was developed and based on as far back as the 1970s. It is interesting to note that naturally-occurring load-carrying and functional materials are based to a very high degree on their structure at the nanoscale. Both wood and concrete are such materials, so one can say that there is a solid tradition for using nanostructured materials in construction.



*TOF-SIMS (Time-of-flight secondary-ion-mass-spectroscopy)
Instrument for mapping the chemical composition of a material within a few nano-meters
(Niels B. Larsen, Risø)*

In this report, we use the concept nanotechnology for technologies which exploit the new possibilities for structuring materials at the sub-micrometer scale – either chemically or physically. At this scale, new properties can be achieved which cannot be created using conventional technology.

We have compared the development in nanotechnology with the need for renewal in construction and come up with six nano-thematic pillars.

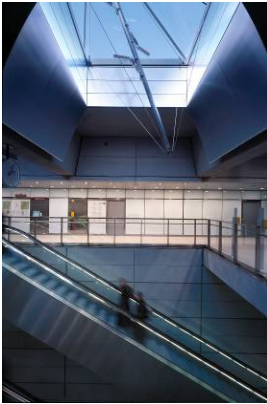
The six nano-pillars are:

1. Nanostructured materials
2. Nanostructured surfaces
3. Nano-optics
4. Nanosensors & electronics
5. Nano-related integrated energy production & storage
6. Nano-related integrated environmental remediation

These pillars form the basis of our mapping of Danish nano-activities in Chapter 3. We have tried to start linking these up with specific construction requirements, but this task needs more work. It entails developing new problem definitions in a long-term dialogue between nano-actors and construction actors.

In Chapter 2, we will first look briefly at the innovation trends and dynamics of nanotechnology in construction. Chapter 3 brings the mapping of Danish nano-construction activities and actors. Chapter 4 seeks to position NanoByg by briefly outlining the main existing institutions and actors of relevance to NanoByg. Chapter 5 discusses policy interests in nano-construction both internationally and in Denmark. Chapter 6 seeks to come up with a set of suggestions for a possible NanoByg initiative.

Appendix 1 contains a case collection that illustrates different applications and potential applications of nanotechnology in the construction industry. Appendix 2 is a broader exposition of the institutional players in the construction industry. Appendix 3 is an exposition of the architectural players and their relation to nanotechnology. Appendix 4 is a summary of the discussion on environmental risk in relation to nanoscience and technology. And in appendix 5 the survey is published.



KHR, Københavns Metro.
Photographer: Ole Meyer



KHR, Københavns Metro.
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KHR, Københavns Metro.
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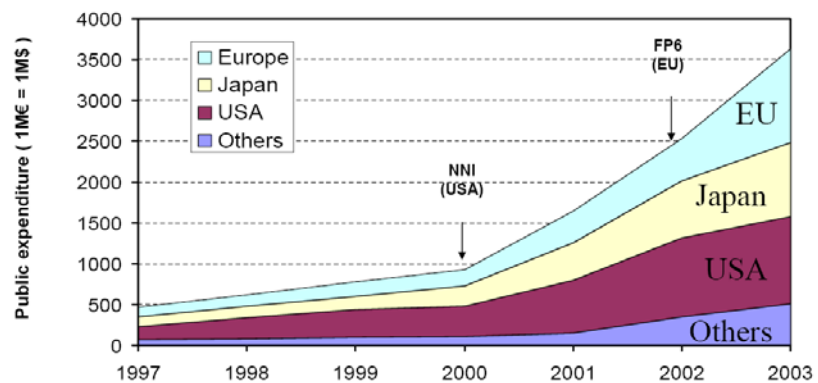
2 Nanotechnology in construction – trends, opportunities and challenges

This chapter briefly discusses some of the main trends and preconditions for the uptake of nanotechnology in construction.

2.1 The Rise of Nanotechnology

Nanotechnology has attracted a huge amount of interest around the globe over the last 5–15 years. The clearest indicator that something special is going on in nanotechnology is investment: it is estimated that in 2004 around USD 9,000m were invested globally in nanotechnology R&D – a trend that seems to be on the increase (Lux Research 2004). Over 30 countries have established nanotechnology R&D programmes in recent years. There is a global race to take the lead in what many expect to be the next industrial revolution, with the US currently in front, but with Asia also very much on the move and the EU lagging somewhat after (Luther, 2004a, Lux Research 2004, Hullmann, 2006). Nanoscale efforts nearly doubled from 1997 to 2000 in both the EU and Japan, and in the US between 2000 and 2004 (Willems and van den Willenberg, 2004). Emerging strong nanotech countries are China, India and Russia.

Public expenditure in nanotechnology is growing by ~40% annually to around 3.5 billion €/€ in 2003.



Source: European Commission (2003)

Table 2.1. Public expenditure in nanotechnology

Innovation research shows that some changes in technology will have such pervasive impact on the economy that they will entail a techno-economic paradigm shift leading to a disruption and renewal of many existing industries (Dosi, 1982; Freeman and Perez, 1988; Perez, 2000, 2002). Nanotechnology is widely considered as such a general-purpose technology (Bresnahan and Trajtenberg 1995, Helpman 1998). Nanotechnology is an enabling technology in the sense that future nanotech breakthrough inventions are expected to have pervasive impact on existing industries and even lead to entirely new industries. Such a possible major industrial transition is likely to take 20–30 years if nanotechnology follows similar

NanoByg



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Tietgen kollegiet. 2003-2005.
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Tietgen kollegiet. 2003-2005.
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Lundgaard & Tranberg.
Tietgen kollegiet. 2003-2005.
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gestation times to those of other general-purpose technologies (Freeman and Loucã, 2001).

Current nanotechnology development is at an early formative stage, characterised by high uncertainty and rapid and radical innovation, a situation that appears analogous to that 25–30 years ago in the two other major general-purpose technologies, biotechnology and ICT, (Freeman and Loucã, 2001). Nanotechnology may more be characterised as a loose technological platform rather than as a technology and indeed many refer to nanotechnologies in the plural (Royal Society, 2004). Technological development is fluid, with uncertain categorisations, and consolidated application areas are only just emerging. This makes it difficult to draw a general picture of nanotechnological development because different sub-areas are in different stages of development.

In some ways, nanoscience is not new; scientists have long had an interest in the nanoscale. What has led to the recent take-off in nanotechnology is the development since the 1980s of new advanced instruments for analysis and manipulation at the nanoscale. Nanotechnology is developing as an interdisciplinary field in the intersection between chemistry, physics, molecular biology and the engineering sciences.

Innovation research on nanotechnology is only beginning to come out, so as yet we know little about industrial uptake except for some general trends. The level of commercialisation varies considerably, but in many areas development is still experimental (Wood, Geldart and Jones, 2003, Lux Research 2004, Cientifica 2003, Federal Ministry of Education and Research, 2004, Luther 2004b, Luhmann, 2006). In the countries most advanced in nanotechnology (US, Japan, Korea, Taiwan), there is considerable industrial involvement and private investment makes up at least 50% of the total. In the US, private investment is at the same level as public investment, and in Japan, private investment makes up as much as 75% of the total (Willems and van den Willenberg, 2004).

In the EU, and this applies also to Denmark, the level of nanoscience is high, but we are somewhat behind the leading countries in industrial uptake of nanotechnology (whether measured in patents, start-up companies and private investments). This is, however, not specific to nanotech, but general for EU innovation patterns (Hullmann 2006).

The large multinational firms are key players in the development of nanotechnology, which underlines the international character of nanotech development. Small start-up companies also play important roles. Most specialised nano-companies are new, with a major take-off in the mid 1990s. But there are also a group of big well-established companies which have expanded their technology portfolio to nanotechnology and play important roles in nanotechnology development, typically in the chemical and pharmaceutical industries (e.g. Bayer, BASF, Carl Zeiss, and General Electrics) (Hullmann 2006).

Forecasts vary greatly. The most well-known is the US National Science Foundation's (2001) forecast of a world market for nanotechnology products in 2015 of USD 1,000,000m, but there are others who are either a lot more or a lot



*Henning Larsens Tegnesteue.
It-Universitet, København,
2002-2004.
Photographer: Adam Mørk*

less optimistic. In other words, it is as yet very uncertain what the future development and scope of nanotechnology will be. However, there are general expectations that nanotechnology is entering a decisive realisation phase over the next 15 years, when markets are expected to grow considerably (Hullmann, 2006).

The hype (and associated science-fiction-like speculation) connected with nanotechnology constitutes a special feature of nanotech development. On the one hand, it means that there are very high expectations of nanotechnology to provide economic growth and new solutions to major problems (e.g. health, environment, energy). On the other hand, there are concerns about risks and ethical issues. There is rising concern among policy makers and nano-actors that nanotechnology may face the same kind of reluctant market acceptance as in the case of GMO (see more on this in the policy section) (Royal Society 2004, Ect 2003, Andersen and Rasmussen, 2006, Andersen forthcoming 2007). But it may be an advantage for nanotechnology that the debate on risks and societal impact is being taken earlier and much more seriously than was the case with biotechnology.

2.1.1 The development of nanotechnology in Denmark

As stated earlier, Denmark has a strong nanoscience base, but relatively modest amounts of industrial nano-activity (Hullmann 2006). This is partly due to the limited role of big industrial players in the Danish economy. Since 2003, public money has been earmarked to nano-research, and this had a major and immediate effect on the Danish innovation system. Several new nano-research centres and networks are springing up or are being reinforced. Today, Danish nanoscience takes place mostly in four big nano-centres: iNANO at the University of Aarhus with links to Ålborg University, the University of Southern Denmark, Nano•DTU at the Technical University of Denmark (merged with Risoe National Laboratory since January 2007) and the Nano-Science Centre at the University of Copenhagen (since January 2007 merged with the Royal Veterinary and Agricultural University). The latter two have recently created an alliance, displaying what for Danish conditions is an unusually high concentration of research activities.

While some of the research groups and sub-centres have been around for a while, some 10–15 years, the nano-centres (using the nano-term) actually named were established in recent years. Also several interdisciplinary “nano-courses” and Ph.D. schools have been established in recent years with great success. A national nano-network, “NaNet”, was established in 2005 with public funding aimed at furthering nano-knowledge exchange and networking (see more on this in Chapter 4).

A mapping exercise carried out in 2005 (Andersen and Rasmussen 2006, Andersen, 2006b) identified 58 predominately Danish companies who were collaborating in some way with Danish nanoscientists. Most of them were small start-ups, but there were also a few of the more established large innovative Danish companies among them. One big company stands out, playing a central role in Danish nanoscience and technology development: Haldor Topsøe, a world-leading producer of environmental catalysts and steam reformers. In the catalysis area, Denmark is in the scientific and technological forefront. Apart from this well-established area (which also feeds into ceramics and hydrogen research), the other

main emerging nano-application area in Denmark is the medical area (Andersen, 2006b). See more on this in Chapter 3.

Case: SCF Technologies

The importance of the focusing process that takes place when a technology meets the market is well illustrated in SCF Technologies. They have developed a "technology [that] makes it possible to use such natural elements as water and carbon dioxide under high pressure and temperature in near/supercritical conditions to create sustainable solutions for such problems for society as obesity, waste disposal and lack of oil" (www.scf-technologies.com).

This shows the enabeling and general-purpose dimensions of nanotechnology in that they have a new technology to treat materials in general, which they then apply to different industrial processes. They can lower the fat in potato chips or produce oil, what they will focus on and develop the most is of course highly dependent upon their encounter with the market. Today they work mainly in three different areas, that is with three different applications: Energy, Food and Advanced materials. However, they only do this as long as there is a development potential within those sectors...

2.2 Nanotechnology in construction

Today we know little of the actual and potential application of nanotechnology in construction. Only four reports are available, all fairly recent reports or papers which more discuss expectations and highlight some cases than bring thorough analysis of trends and impacts (see Gann, 2003, Bartos et al., 2004, Nanoforum 2006, VDI 2006). Two international nanoconstruction symposiums have been held in recent years, see www.nanocem.org

"If construction continues to ignore nanotechnology it will be the one left paying a fortune for a last minute ticket it could have had for a song if it had acted earlier"

(Nanoforum p.5, 2006).

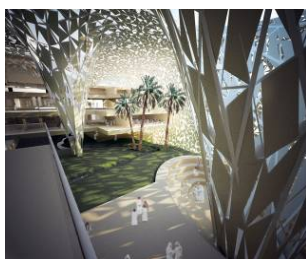
The main conclusion from the mentioned analyses is that there is a considerable but underexploited potential for nanotechnology in construction. Since materials are construction's core business the sector is expected to be an important beneficiary of new nanomaterials. In the Nanoforum report a survey among international nanoconstruction experts predicted that many nanoadvances would arrive in construction within five years (Nanoforum 2006). The sheer size and scope of the construction industry means that the accompanying economic impact will be huge.

2.3 Innovation in construction; Opportunities and challenges

The construction industry has often been accused to be a low-tech industry weak in innovation. An overall conclusion to the development of the industry is thus that productivity and the rate of innovation has been considerably lower in the



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construction industry compared to the economy as a whole during the last 20 years. (EBST, Byggeriets fremtid - fra tradition til innovation)¹. Accordingly, the percentage of R&D of turnover is considerable lower for the building and construction industry compared to the Danish industry as a whole, as shown in the figure below. Furthermore the investment in R&D has been declining in recent years.

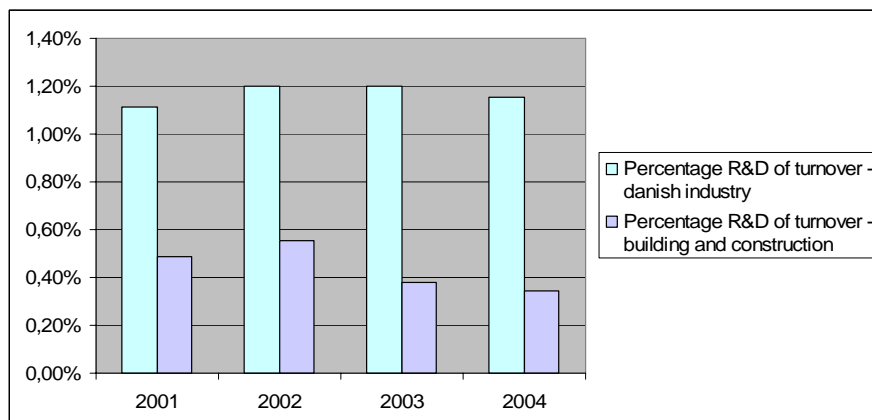


Table 2.2: percentage R&D og industry turnover
Source: R&D figures are from Dansk Forskningsstatistik.
Turnover figures are from Danmark Statistik.

As elaborated below, innovation in construction is conditioned by some very fragmented and complex organisational structures, which distribute opportunities, risks, willingness and resistance uneven across different actors throughout the value chain. To support innovation it is thus necessary to be both strategic and creative in order to establish coherent and dedicated networks or alliances of actors and resources.

In 2004 the total production value of the construction industry was 448,7 billion dkk. In total the sector employed 305.673 persons.

(Statistics Denmark, www.statbank.dk)

¹ http://www.ebst.dk/publikationer/rapporter/byg_frem/index.html

Some of the most commonly identified challenges to innovation in construction are:

1. A long value chain
2. Project based production
3. Organizational fragmentation
4. Different incentives and interest along the value chain
5. Rigid regulatory standards
6. Lack of international competition
7. A long value chain

A key issue in order to understand (the lack of) innovation in construction is the actual length and complexity of the value chain. Building materials are part of established heterogeneous ad hoc networks of design, retailers, manufacturers, building production and consumer interests which can be a barrier to the introduction of new materials. In order for an innovation to succeed knowledge, competences and support needs to be dispersed among a wide range of players.

Project based production

The project-based production on the building site is a fundamental characteristic of the construction industry (Gann and Salter 2000). This can be an important barrier to innovation, as experiences are not easily used across individual building projects. A hindrance to systematic learning is that the constellation of players is often unique in each project. The decoupling between project and enterprise is another barrier to learning across projects (Winch 1998).

Organizational fragmentation

The project-based production of the construction phase is characterized by a complex organizational and technological fragmentation into various trades with different capabilities. In order to cope with this fragmentation new products often merely replaces conventional products (Erhvervsministeriet 2000). Radical change cannot take effect without affecting the traditional organization of the construction phase.

Different incentives and interest along the value chain

The development and diffusion of technological solutions often presupposes cooperation along the value chain. Different incentives and interests along the value chain hinder such cooperation. An example is that the contractors incentive to engage in development projects with material manufacturers are often limited, as the ownership of the innovation goes to the material manufacturer. The contractor furthermore bears the main risk when new materials are introduced². An additional problem is that existence of very stable relations between contractors and wholesale dealers of building materials hinder efficient competition, leading to high prices and low entrance of new materials (EBST 2004).

² Interview with Lars Blåbjerg, NCC

Rigid regulatory standards

Some types of regulations support the use of traditional and well established materials. It has been argued that the Danish fire-code has been an obstacle to wooden buildings and the development of new insulation materials (Clausen 2002).

Regulatory standards generally play an important part in construction, often inhibiting innovation (see also chapter 4 on policy). At the European level much work is being done in order to establish common regulatory standards furthering the international competition on building materials. Generally speaking the traditional strong home market orientation of the Danish construction industry is beginning to be challenged by the rising globalisation of the economy. There is an early burgeoning, but silent, industrialization on the way. Modular construction systems are rising, e.g. in wooden houses or new materials such as glasfiber, prefabricated bathrooms or kitchens are being installed etc., often manufactured in cheap Eastern European countries.

3 Mapping analysis of Danish nano-construction activities and actors

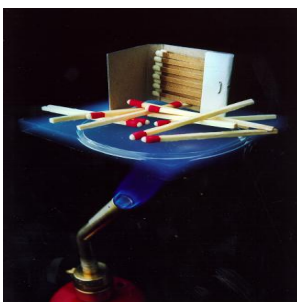
3.1 The aim of the mapping



A 2.5 kg brick is supported on top of a piece of aerogel weighing only 2.38 grams (NASA)

This chapter brings an analysis of Danish nano-activity relevant to the construction sector. We asked nanoscientists and nano-active companies about activity they are engaged in that either is or *could become* relevant for construction. The results of this analysis are presented below in a condensed form in a series of matrixes. Since very few Danish construction actors (scientists or companies) are active in nanotechnology today, the construction sector is little represented in the matrixes. But we also tried to inquire into the needs of the construction industry and its expectations with regard to nanotechnology. The results of this inquiry are presented in the succeeding discussion.

The overall conclusion from the mapping exercise is that the expected gap between nanotechnology and construction has been confirmed. Danish nano-actors are not very active in the construction sector and know little about its needs, and the construction sector is even less active in nanotechnology and knows very little about its possible implications for the sector. We will seek to expand on this conclusion in more detail below.

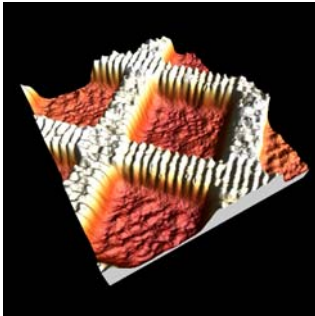


Matches On Aerogel Over A Flame

Another photo illustrating the excellent insulating properties of aerogel. The matches on top of the aerogel are protected from the flame underneath.

The lack of insight on both sides weakens the empirical findings in this chapter. Many nanoscientists and nano-companies found it difficult to be very specific about how their work could be applied in construction. It was similarly difficult for the construction sector to identify the potentials in a technology they know little about. The findings on nano-construction potentials should therefore be seen as just a first rough estimate. For the same reasons, quite a lot of actors, particularly on the nano-side, declined to participate in the mapping exercise because they could not relate to construction and thought they had little to contribute. Often nanoscientists and companies were persuaded to participate, but only after more in-depth dialogues on the perspectives of nano-construction. So the current mapping cannot be said to cover all the potential nano-actors whose work is of interest to construction – for that more in-depth studies and dialogues are needed – but certainly the more obvious ones are included.

The mapping seeks to give a general and comprehensive picture of all major Danish nano-activity combined with a discussion about its actual and possible relevance for construction. The intention is to illustrate and specify the many diverse nano-activities at a quite concrete scientific and technological level.



AFM (atomic force microscopy) picture of an injection molded biocompatible nanostructured surface (polycarbonate) mimicking a collagen structure (Niels B. Larsen, Risø)

We compared developments in nanotechnology with the need for renewal in construction and grouped the results into six nano-thematic pillars:

1. Nanostructured materials
2. Nanostructured surfaces
3. Nano-optics
4. Nanosensors and electronics
5. Nano-related integrated energy production and distribution
6. Nano-related integrated environmental remediation

More general nanoscience and manufacturing work of less direct relevance to construction are mapped in a remaining group:

7. General nano-science and competencies

Some areas could be divided into two or more groups depending on whether the focus is on the nanotechnologies or the application.

The main findings in each of these pillars are presented in a dense matrix below followed by a short analysis. Each matrix presents:

Column 1: A short description of the nanoscience/technology area and possible sub-areas/key research themes (indicated with a -).

Column 2: Its application and relevance for construction, indicating both current main industrial application focus for the science/technology area (in various industries including construction) as well as expected potential relevance or use in construction. The development stage of the area is stated.

Column 3: The companies working with the area (both in and outside construction). The companies have either contributed directly with input or have been named as collaboration partners by Danish nanoscientists. Their involvement may vary considerably from serious nano-R&D to just early informal dialogues with nanoscientists. Foreign companies who are important collaboration partners are also listed. The comparative strength of the area is stated, i.e. the international importance of the Danish activity, – based on the actors' own estimations.

Column 4: The main Danish nanoscientists working in the area and their affiliations.³

3.1.1 Methodology

There are several different sources for the data used in this chapter. We have drawn on and added to an earlier general mapping of Danish nano-activity from

³ The affiliations in the matrixes refer to the Danish nanocentres or other knowledge institutions: *Nano•DTU* at the Technical University, *iNANO* at University of Aarhus (AU) and University of Aalborg (AAU), *NSC NanoScience Center* at the University of Copenhagen, and *NanoSyd* at the South Danish University, *Risoe*, Risoe National Laboratory, *TI* Technological Institute. *CU* Copenhagen University. Names in italics are from the 2005 mapping exercise.



*A Picture from the new clean room at Risø called CleaR. It can be used to create nanostructures in soft materials as for example polymers. (Risø)
Photographer: Lars Bahl*

2005 which was carried out as part of a green nano-forecast made for the Danish Ministry of the Environment (see Andersen and Rasmussen, 2006, Andersen, 2006b). This mapping gives quite a complete picture of Danish nano-activity and therefore is a good basis for further analysis.

On top of this, we have added a more construction-specific analysis based mainly on an electronic survey but also on inputs from interviews and cases. The survey was aimed at the more nano-active/competent scientists and companies (see the survey in appendix 5). Approximately 60 researchers and companies in total filled out the survey. The electronic survey was not only sent to the NanoByg contact list, but also to the Danish nano-centres (Nano•DTU, iNANO, NanoScience Center, and Nano SDU⁴, either by direct contact with known relevant researchers or through their appointed nano-coordinators. Nanoscientists were also contacted directly at Risøe (merged with DTU since 1/1 2007), the Royal Veterinary and Agricultural University (merged with University of Copenhagen since 1/1 2007) and the University of Roskilde, as well as at all Danish "Approved Technological Service Institutes". This means that all Danish nano-relevant knowledge institutes have been included in the mapping. Unfortunately participation has been somewhat uneven. At Risøe, from where the mapping was undertaken, a large number of nanoscientists were contacted directly and there was a close follow up, which has resulted in an overrepresentation of Risøe contributions. In general there was a low response to the electronic distribution of the survey and a much higher response to the bilateral contacts. Since it is always hard to make (busy) people respond to surveys, this is not so surprising, but the lack of insight in construction made it more difficult to attract interest. A few centres or institutes did not participate at all or in a very limited way, and in these cases we relied on the data from the earlier general mapping (e.g. the NanoScience Center at the University of Copenhagen, which is very medicine oriented, and the Technological Institute which has shown little interest in the NanoByg idea).

Some companies were reluctant to contribute to the survey or the cases, either because they felt they had insufficient nano-expertise or because they were unwilling to reveal their nano-activity. Unfortunately, this means that there are a few companies that are quite active in nano-construction but are not fully included in the analysis. However, most are mentioned in the matrixes. There is more on this in the succeeding sections on interests in nano-construction.

⁴ The mentioned nanocentres are situated at the following universities: Nano•DTU at the Technical University, iNANO at University of Aarhus and University of Aalborg, NanoScience Center at the University of Copenhagen, and Nano SDU at the South Danish University as discussed further in chapter 4.

3.2 Mapping of Danish nano-expertise in construction

In the following we will focus on the Danish findings in each nano-pillar in turn.

3.2.1 Pillar 1 Nanostructured materials

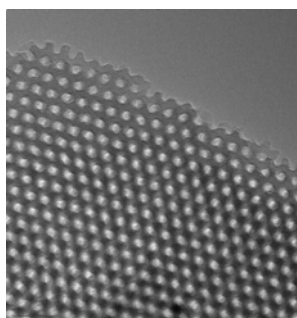
1 Nanostructured materials:			
1.1 Composites	Applications and relevance for construction	Companies	Nano scientists
1.1.1 Biocomposite materials from renewable resources Nano-scale reinforcement of biodegradable polymers (e.g. PLA, PHBV, PCL, starch) with inorganics (e.g., clays) or micro-fibrillated cellulose (MFC). - Plant fibres with nano-structured surfaces for improved interfaces in composites. - Polymer nanofibres (self-assembled and self-reinforced). - Nanocomponents as sensors in composites.	Application focus: Medical, electronics, textiles, clothing, windmill wings. Potential in construction: Biodegradable, and energy and resource efficient biocomposite materials with improved macroscale properties (strength, lightness, thin) in building applications. Development stage: 5-10 years to market.	Færch Plast Novamont <i>NKT Flexibles</i> <i>Vestas</i> <i>NEG Micron</i> <i>LM Glasfiber</i> Comparative strength: Medium level, many research activities in Denmark.	B. Madsen, Risoe D. Plackett, Risoe H. Lilholt, Risoe H.C.B. Hansen, NSC R. Pyrz, iNANO, AAU A.B. Thomsen, Risoe B.F. Sørensen, Risoe P. Kingshott, iNANO, AU A. Boisen, Nano•DTU K.W. Jacobsen, Nano•DTU R. Feidenhans'l, NSC <i>H. M. Jensen, AAU</i>
1.1.2 Nanocomposites Controlling and reinforcing composite properties by adding nanoscale particles. - Controlling bond between fibre and matrix in composites. - Manufacturing and characterization of polymer based nanocomposites with nanowires and nanotubes.	Application focus: Various, [shipbuilding, mining]. Potential in construction: Insulation material based on nanocomposites with improved insulation, strength and lightness. Development stage: Early commercial market.	Fibertex A/S LM Glasfiber A/S NKT Flexibles I/S Færch Plast Novamont Rockwool A/S VELUX A/S Sumitomo Electrics STUBA, Slovakia Comparative strength: Pioneering in the world.	K. Almdal, Risoe T.L. Andersen, Risoe R.Pyrz, iNANO, AAU J.S. Thomsen, AAU J.C. Grivel, Risoe D. Plackett, Risoe P. Bøggild Nano•DTU A. Boisen Nano•DTU C.H. Christensen, Nano•DTU K.W. Jacobsen, Nano•DTU

1.1.3 Fibre reinforced materials Composite materials with optimized fibre/matrix interface resulting in improved mechanical properties and durability. - Fundamental understanding of fibre/matrix interface on the nanoscale.	Application focus: No specific focus so far, windmills, some limited use in construction. Potential in construction: Light, thin, strong materials, e.g. substitute for glass fibre, steel and other metals. Load carrying materials, thermal insulation, electrical insulation. Easier to mount, possibility for new designs, more durable materials and cheaper maintenance. See Case 1.3, 1.4, 1.5 and 1.10. Development stage: 5-10 years to market.	Velux A/S Fiberline Composites A/S Fibertex A/S LM Glasfiber A/S NKT Flexibles Gurit Scandinavia Aps Vestas NEG Micron LM Glasfiber	K. Almdal, Risoe T.L. Andersen, Risoe R.Pyrz, iNANO, AAU J.S. Thomsen, AAU J. Drews, Risoe A.B. Thomsen, Risoe B.F. Sørensen, Risoe B. Madsen, Risoe H. Lilholt, Risoe P. Kingshott, iNANO, AU A. Boisen, Nano•DTU K. Jakobsen, Nano•DTU R. Feidenhans 1, NSC H.M. Jensen, AAU
1.1.4 Cement based materials Nanostructure modification of cement based materials, e.g. concrete, through process control and the use of nanosized additives. Examples: - Characterisation and modification of atomic and nano-structure, nanosized additives and hydration products including pore structure and state of water. - Characterization and modification of reinforcement of cement based materials (see also fibre reinforced materials). - Modelling of moisture transport, solid solution reactions in the C-S-H gel, and diffusion of ionic species.	Application focus: Structural, protective, products as pipes, tiles etc; Potential in construction: Cement based materials with tailored properties (workability in fresh state, mechanical properties, durability, aesthetics, other functional properties) based on improved understanding of structure-properties relations on the nano- to macroscale. Improved corrosion resistance of reinforcement. See Case 1.1 and 1.9 Development stage: 0-5 years.	Aalborg Portland A/S, Densit 4K Beton H+H Celcon A/S Saint Gobain (Fr)	J.Skibsted, iNANO, AU T.R. Jensen, iNANO, AU M. Geiker, BYG•DTU & Nano•DTU S. Lundsted, iNANO, AU T. Kristensen, iNANO AU K.K. Hansen, BYG•DTU & Nano•DTU H. Lindgreen, GEUS P. Møller, Nano•DTU B. Johannesson, BYG•DTU NN, Force
1.2 Wood based materials	Applications and relevance for construction	Companies	Nano scientists
1.2.1 Wood based materials Ultra nano-scale structural modification of wood. - Service life models for wood frame structures.	Application focus: Textiles Potential in construction: Modification of wood for improved biological resistance giving durable wood construction materials with lower maintenance. Basis for performance based design of wood structures (regarding safety and reliability, sustainability, serviceability incl. aesthetics). See Case 1.6. Development stage: 5-10 years to market.	Ecobinder WPT technologies VELUX A/S Comparative strength: Pioneering in Denmark.	C. Felby, Forest & Landscape, CU D. Plackett, Risoe S. Svensson, BYG•DTU L. Thygesen, BYG•DTU P. Hoffmeyer, BYG•DTU
1.3 Nanoporous materials⁵	Applications and relevance for construction	Companies	Nano scientists
1.3.1 Ceramic insulation Ceramic nanoporous tiles (ceramic processing) for high insulation capacity.	Application focus: High-effective insulation materials, used in space shuttles. Potential in construction: Novel insulation material. Development stage: Products but very costly, potential research idea.	Comparative strength: No Danish research so far but basic know how.	M. Mogensen, Risoe XXXX
1.3.2 Nanoporous polymer materials Via self organisation at nanoscale and	Application Focus: General, medical, pharmaceutical.	SCF Technologies Radiometer A/S	S. Ndoni, Risoe K. Mortensen, Risoe

corrosion creating a unique homogenous cavity structure.	Potential in construction: Development of functional nanoporous materials based on block polymers for sensor, indoor climate and surface applications. E.g. membranes, electro osmotic pumps, controlled release and diagnosis. Development stage: Early experimental.	Merck Chemicals PSI Switzerland Comparative strength: Among pioneers (also 4 -5 places in USA, Japan).	J.W.Andreasen, Risoe M.E.Vigild, Nano•DTU
1.3.3 Zeolites Development of organic/inorganic networks, metalphosphate lattice structure zeolites.	Application focus: Used for catalysis, gas storage, gas separation, chemical synthesis. Potential in construction: Catalytic cleaning Development stage: Commercial, zeolites are used in large quantities industrially. See also "Gas storage".	Haldor Topsøe A/S Comparative strength: Research in front.	B.B.Iversen iNANO AU T.R. Jensen, iNANO AU J.E. Jørgensen, iNANO, AU H. Birkedal, iNANO, AU C.H. Christensen, Nano•DTU T. Bligaard, Nano•DTU H. Lauritzen, TI
1.3.4 Thermoelectric materials For cooling or energy production based on host/guest materials with nanovoids.	Application focus: Various. Potential in construction: For cooling or energy production integrated in buildings. Development stage: Early? Used today by NASA. New breakthrough may change cooling and/or energy conversion in a fundamental way.	SCF Technologies VELUX A/S Danfoss Grundfos Comparative strength: Research in front.	B. B. Iversen, iNANO, AU L. Rosendahl, Energiteknik, AAU G. Madsen, AU
1.3.5 Monolithic silica aerogel Nanostructured monolithic silica aerogel as open-pored transparent materials with good insulation properties. - Coal doped nanostructured aerogel used as spacers for vacuum insulation panels.	Application focus: Insulation materials, windows. Potential in construction: Application of high optical transmittance nanostructured monolithic silica aerogel as insulation materials in windows. Many other applications in refrigerators, freezers, coolers, as building insulation, substrate for catalytic materials, gas filters, waste encapsulation and membranes. Development stage: For windows: Prototypes, estimated time to market is 5-7 years.	VELUX A/S Velfac SCT Technologies Airglass, Sweden Comparative strength: Unique expertise in handling monolithic silica aerogel.	K.I. Jensen, BYG•DTU J.M.Schultz, BYG•DTU
1.4 Polymers	Applications and relevance for construction	Companies	Nano scientists
1.4.1 Bioplast Polymer materials based on organic materials, permeability changes by addition of nano composites. Use of (nano) clay particles, sometimes in modified form. - Bioplast is degradable and replaces fossil fuel resources of conventional plast.	Application focus: Packaging, medicine. Potential in construction: Bioplast are used in biocomposites as matrix material (see biocomposites). Potential use for insulation materials, other building elements, and electronic equipment. Development stage: Early, some products are in production, but short durability. For bulk (packaging) as well as refined products.	Arla Foods Færch Plast Comparative strength: The nano part of bioplast is a new research area.	D. Plackett, Risoe V. Holm, Faculty of Life Sciences, CU P. Ulvskov, Faculty of Life Sciences, CU H.V. Scheller, Faculty of Life Sciences, CU A. Blennow, Faculty of Life Sciences, CU S.B. Engelsens, Faculty of Life Sciences, CU

1.4.2 Conducting polymers (CP) Polymers are good insulators but the special class of polymers, CP, have conductivity levels between those of semiconductors and metals. - New methodologies for integrating and patterning CP layers into the surface of bulk polymers. Integration occurs via solvent-induced blending of a nanoscale thickness CP layer into a thermoplastic polymer surface.	Application focus: Electronics, corrosion protecting coatings. Potential in construction: The combination of metallic and polymeric properties opens completely new opportunities in numerous applications, particularly in the electronics industry. - Antistatic surfaces on glass and polymers. - Smart window technology. E.g. use of CP to switch between bleached and coloured through an applied voltage. For solar control (light and heat). Development stage: Full commercial use within electronics and for corrosion protection	H.C. Starck, Baytron Comparative strength: Many research activities in DK.	N.B. Larsen, Risø K. West, NSC P. Møller, DTU J. Bech, TI T. Bjørnholm, CU K. Bechgaard, CU
1.4.3 Memory polymers Memory polymers are materials that react by changing form or size from stimulus like light or heat.	Application focus: Medical, mechanical devices, textiles. Potential in construction: Design of building elements with new functional properties e.g. dynamic wall membranes for use in solar control, climate control, acoustic regulation etc. See Case 1.2. Development stage: Full commercial use within medico and for mechanical devices	Henning Larsens Tegnestue Septum A/S Comparative strength: Very little research in DK.	P. S. Larsen, Risø H.H. Lund, SDU J. Bech, TI
1.5 Other Materials	Applications and relevance for construction	Companies	Nano scientists
1.5.1 Organic molecular nanoaggregates The generation of new, tailored organic molecular nanoaggregates with specific integrated functions for electrical/lighting system. Nanofibers that generate intense light (coherent) of specified color. Very high quantum efficiency, frequency converting possibility, high electrical mobility, morphologically well defined.	Application focus: Transportation Potential in construction: Integrated functions for electrical/lighting system. Labeling of specific objects with nanolabels. Development stage: Early introduction to market	Nanofiber A/S Stensborg A/S Comparative strength: Pioneering in Denmark.	H.G. Rubahn, NanoSYD

Table 3.1. Pillar 1 Nanostructured materials:



Electron microscopy picture of a nanoporous polymer material based on a block copolymer.
(Sokol Ndoni, Risø)

The pillar of nanostructured materials represents a large group of research and technology areas of great importance for the construction sector. It covers six different subgroups (composites, wood, nanoporous materials, polymers, monolithic silica aerogel and other materials), which again can be subdivided into 16 sub-areas, illustrating the great diversity of nanotechnologies. Some examples from this area are mentioned below.

Already applied in construction and an area attracting considerable recent interest and nanoscience funding in both Denmark and internationally is *cement*-based materials with tailored properties based on improved understanding of structure-properties on the nano- to macroscale. The area is interesting not least because Denmark is in the technological and scientific forefront in this area and with strong commercial activity (e.g. Aalborg Portland, see case 1.1.) and active participants in the international NanoCEM research initiative (see chapter 4 on positioning for more on this). Recent and ongoing Danish research shows that nano-sized clay particles can significantly change the porosity of hardened cements and the rheology of the fresh concrete, this last improving the self-compacting properties of concrete when used e.g. the production of concrete elements, see cases 1.1. and



KHR, Fiberline.
Photographer: Torben Eskerod.



KHR, Fiberline.
Photographer: Torben Eskerod.



KHR, Fiberline.
Photographer: Torben Eskerod.



KHR, Fiberline. Photo: KHR

1.9. Ongoing Danish research support expectations of future important improvements e.g. new types of more sustainable cement, improved corrosion resistance of reinforcement, and self-cleaning surfaces of concrete structures.

The group of *composites* presents options for new construction materials with interesting properties such as strength, lightness and thinness particularly in connection with modular construction processes. *Fibre-reinforced materials* are among those already to a limited degree being applied in construction and civil engineering, cf. the Danish company Fiberline, see cases 1.3, 1.4., and 1.5. which has come up with a series of novel material solutions in Danish construction. While there is much research in composites in Denmark, the nanoscience part of this research could be strengthened, not least in relation to industrial applications in construction. The *nanocomposites* are currently not used much in construction except for the non-woven fibres of the Danish company Fibertex, where they experiment with the use of nanotubes and nanoclay, (c.f case 1.5). Danish experiences from e.g. windmill production could be used in other construction and civil engineering. The biocomposites are today mainly aimed for other industrial areas, e.g. packaging, but are interesting not least because of their potentially great environmental benefits as well as aesthetics which could be put to good use in construction.

Wood is another key building material. A nano-scale structural modification of wood is a new research area in Denmark, but potentially highly interesting as it could remedy some of the problems with using wood in construction, e.g. it could improve biological resistance giving durable and safer wood construction materials with lower and more environmentally-friendly maintenance.

The group of nanoporous materials is another potentially very interesting group, not used very much in Danish construction today. These materials show interesting new properties which could be used in e.g. insulation both in walls and windows, [air-cleaning/self-cleaning materials] and for cooling and energy conversion. Some of these are at an early stage of development while others are commercially available. The thermoelectric area, ceramic insulation and zeolites build on the underlying catalysis/ceramics nano-expertise in which Danish nanoscience leads the world, which makes these areas potentially very interesting. More development needs to take place though to make this research relevant to construction. See e.g. the cases 1.1-10.

The polymers are a group of nanomaterials which could potentially offer smart novel material solutions in construction, but which are currently little used. E.g. for *conducting polymers* the combination of metallic and polymeric properties opens up for new options such as solar control in windows through an applied voltage. The *memory polymers* change form or size from stimuli like light or heat and could contribute to e.g. dynamic wall membranes for use in solar control, climate control or acoustic regulation.

Also the *organic molecular nanoaggregates* could potentially bring new solutions in construction. These nanofibres generate intense and coherent light of specified colour and could be used in integrated functions for electrical/lighting systems.

3.2.2 Pillar 2. Nanostructured surfaces

2 Functional surfaces:			
2.1 Chemically modified surfaces	Applications and relevance for construction	Companies	Nano scientists
2.1.1 Surfaces with active nanoparticles Surface coatings and modifications for improved resistance against dirt and bacteria. -Production of photocatalytic nanocrystalline materials using supercritical high pressure technology. - Visible light photocatalysts.	Application focus: Mainly food and medico, but various, chemical, mining, wood & paper, limited construction. Potential in construction Surface treatments of construction material that facilitate cleaning without affecting the aesthetic appearance or decreasing the durability of the material. Will also result in prolonged lifetime of the building materials. - Anti-fouling, self cleaning surfaces (e.g. windows), antibacterial surfaces. - Self-lubricating surfaces with reduced wear and tear. Potential for water/waste water cleaning. Environmentally friendly paint for ships. See Cases 1.5, 2.1-3, 2.5, 2.7 and 7.2 Development stage: Early production, larger production expected within 10-15 years.	SCF Technologies Grundfos Skiold K.G. Jørgensen, 3XN Ramboll Hempel SAPA Danfoss Danisco Fibertex A/S VELUX A/S Mærsk LEGO B&O NCSU Dansk Tagteknik Comparative strength: Close to front.	P. Møller, DTU F. Besenbacher, iNANO AU P. Kingshott, iNANO, AU P. Bøggild, Nano•DTU H.N. Hansen, Nano•DTU L.P. Nielsen, TI T. Zwiag, TI K.D. Johansen, DTU J. Lorenzen, TI
2.1.2 Natural anti-fouling Use of natural antibacterial agents for surface modification.	Application focus: Medical, fishing industry Potential in construction: Safe and eco-efficient use of various surface treatments with intended moisture and dirt interactions. Development stage: Very early/infant, but not far from market (5-10 years).	Fibertex A/S Ramboll SMB Comparative strength: Among pioneers.	P. Kingshott, iNANO, AU L. Gram, Institute for Fisheries.
2.1.3 Plasma treated surfaces Plasma treatment with monomers resulting in functional surfaces.	Application focus: Medico Potential in construction: Can be used for producing corrosion resistant surfaces and potentially to improve adhesion between materials (e.g. fibre and matrix in composites) to make stronger materials. - Anti-fouling & antibacterial surfaces. - New coatings w. functionalized polymers, e.g. switchable coatings. - Water repellent construction surfaces. See Case 2.6 Development stage: Established industry.	SMB Nanon Coloplast Comparative strength: Medium level, many research activities in Denmark.	M. Foss & F. Besenbacher, iNANO, AU N.B. Larsen, Risoe P. Kingshott, iNANO, AU J. Schou, Risoe N. Theilgaard, IT
2.1.4 Coatings with biomolecules Immobilization of peptides, proteins, and enzymes on surfaces. - Chemical synthesis of complex, bio-active molecules. - Coating with bio-layers.	Application focus: Medico Potential in construction: It Can make Anti-fouling & antibacterial surfaces. Can be used in biosensor application. Water repellent construction surfaces. Development stage: Established industry.	SMB Coloplast Nunc Comparative strength: Medium level, many research activities in Denmark.	A. Boisen & M. Dufva, Nano•DTU, J. Ulstrup, Nano•DTU, M. Foss og F. Besenbacher, iNANO, AU N.B. Larsen, Risoe P. Kingshott, iNANO, AU J. Schou, Risoe N. Theilgaard, TI K.J. Jensen, Faculty of Life Sciences, CU

2.2 Physically modified surfaces	Applications and relevance for construction	Companies	Nano scientists
2.2.1 Nanostructured amorphous alloys Production of controlled micro and nanostructures in amorphous alloys for sensor applications.	Application focus: Pharmaceutical, environmental. Potential in construction: Can be used in production of sensors for e.g. indoor climate control. Development stage: 5-10 years to market.	Novo Nordisk, Oticon, Sonion, Pinol Comparative strength: Pioneering in the world.	T. Andersen, Risoe J. Schiøtz, Nano•DTU
2.2.2 Nano crystalline coatings Superhard nanocrystalline oxide or metal coatings with large thermal and chemical resistance.	Application focus: Surface coatings of tools? Potential in construction: Hard and durable surfaces. Corrosion and temperature resistant coatings. See Case 2.3 Development stage: Early commercial use.	SCF Technologies Grundfos Comparative strength DK: Research in front.	J. Bøttiger, iNANO, AU R. Pyrz, iNANO, AAU B.B. Iversen, iNANO, AU L.P. Nielsen, TI
2.2.3 Pulsed laser deposition Pulsed laser deposition (PLD) is used to produce high quality films of nm-thickness. These are oxides and metal coatings with special electrical, magnetic and optical properties.	Application focus: For optical communication, sensor devices and SOFC (solid oxide fuel cells). Potential in construction: sensors XX Development stage: Experimental prototype nanofilm systems, allows for fast production but currently too expensive for wider commercial use.	Comparative strength DK: Using new PLD equipment among European top ten.	J. Schou, Risoe N. Pryds, Risoe
2.2.4 LCD (Liquid Crystal display) Window for solar and daylight control applications, based on films of polymer-/liquid- crystal composites.	Application focus: General, chemical, windows. Potential in construction: LCD windows - Second generation liquid crystal windows for fast and effective solar control in buildings – so called smart windows. - Higher energy efficiency though 3 operating modes: selective reflective (limiting overheating), transparent, and scattering. Fast response times independent of the glazing surface. Development stage: Prototypes, estimated 5-7 years to market.	VELUX A/S Comparative strength: Research into the metrology as part of EU project.	K.I. Jensen, DTU T.T. Alkeskjold, Nano•DTU, F.H. Kristiansen, BYG•DTU J.M. Schultz, BYG•DTU
2.2.5 Electrochromic coatings Coatings with electrochromic materials opens/shuts for the sun or change colour.	Application focus: ? Potential in construction: Intelligent windows/boards/signs. Allows for better energy efficiency in buildings and civil works. Development stage: Early stage research, only little activity.	VELUX A/S <i>Velfac</i> Comparative strength:	M. Mogensen, Risoe K. West, NSC
2.2.6 Topological nanostructured surfaces Nanoporous membranes with selective permeability to short-chained carboxylic acid. - Laser treatment. - Replication of nano structures in metals and polymers. - Membrane production (see bio-separation). - Nanoparticles for paint that forms a homogeneous 3-D network structure.	Application focus: food & medico Potential in construction: Achieve strong surfaces (thermal stable, wear ability), & anti-fouling properties. Nanoporous membranes with selective permeability for separation processes. Water repellent construction surfaces See Cases 2.4 and 2.5. Development stage: Patents with external partners, on its way to be accepted by industry (food & medico). Within 2-5 years, larger market is expected.	BASF DK Ramboll <i>Glud & Marstrand</i> <i>Radiometer</i> <i>Lego</i> Comparative strength: Close to front.	H.G. Rubahn, NanoSYD K.S. Jensen, Risoe M. Foss, iNANO, AU P. Balling, iNANO, AU K. West, NSC N.B. Larsen, Risoe H.N. Hansen, Nano•DTU A. Kristensen Nano•DTU Per Møller, Nano•DTU L. H. Christensen, TI T.M. Hansen, TI

Table 3.2. Pillar 2 Nanostructured Functional surfaces.



Henning Larsens Tegnestue.
Bølgen i Vejle, 2006-2009,
Visualisering: HLT

The pillar of nanostructured surfaces represents an equally potentially very important nanotech area for construction; not least because it can address some of the important challenges construction faces in renovating existing buildings worldwide. This is a large group, divided into respectively chemical and physically modified surfaces, which again are subdivided into ten subcategories, illustrating a very diverse set of nano-techniques. Some of these techniques are in an early stage of being applied in construction – mainly in concrete, glass and steel – but in Denmark most have other main application foci, again with medicine as the dominant focus.

Some main points are:

Among the chemically modified surfaces, surfaces structured with *active nanoparticles*, make up a substantial and advanced nanoscience area in Denmark with products already commercially available and with quite a lot of Danish industrial activity too, including a few construction companies. They may strengthen such important properties as anti-fouling (including anti-graffiti), self-cleaning (e.g. for windows), self-lubricating (e.g. for pumps) and self-healing and antibacterial surfaces in construction. But the paints developed in Denmark are currently more used in ships than in buildings or windows, and the antibacterial coatings are more used in medicine (e.g. implants) than in e.g. kitchens, bathrooms or hospitals. The most widespread use of nanoparticles in construction worldwide today is currently the TiO_2 coatings. These particles catalyse very powerful reactions, which break down bacteria, algae, fungi, smog, odours, etc. Through photocatalytic processes, they can break down organic and inorganic air pollutants, which mean that coated roads and buildings could be used for environmental remediation.⁶ TiO_2 is also hydrophilic and is used commercially today in self-cleaning windows and tiles.⁷ The company, SCF Technologies, has commercial products available for self-cleaning and anti-fogging coatings for windows. While photocatalysts normally only work under exposure to UV light and therefore outdoors, SCF Technologies is working on the development of visible light photocatalysts, which opens up for wider indoor application options in construction.

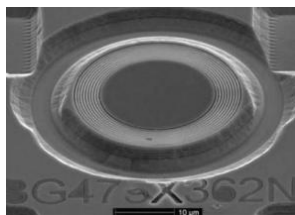
Within concrete there is growing research into applying nanostructured surfaces, e.g. Ålborg Portland is engaged in recent development here, see case 1.1.

Other interesting coatings are the *plasma treated surfaces* which can lead to corrosion-resistant surfaces, the subgroup *functionalised polymers*, which can be used to make switchable coatings. Today the main application focus is medical though.

Among the physically modified surfaces, there is advanced work on the hard nanocrystalline coatings of interest for construction. The company SCF Technologies

⁶ E.g. a coating of a 7000 m² road in Milan gave a 60 pct. reduction in nitrous oxides (Nanoforum 2006)

⁷ The British company Pilkington has commercial self-cleaning windows on the market, possible among the most known nanoproducts used in construction today, but not much used in Denmark so far.



Researchers at the National Institute of Standards and Technology (NIST) have made semiconductor light-emitting diodes (LEDs) more than seven times brighter by etching nanoscale grooves in a surrounding cavity to guide scattered light in one direction.

July 17 issue of *Applied Physics Letters*.
Credit: NIST

also has commercial products here which are ultrahard, corrosion- and temperature-resistant ceramic coatings.

The LCD (Liquid Crystal display) films of polymer/liquid-crystal composites are highly interesting as they can lead to smart and energy efficiency windows. There is some Danish research into this in connection with EU research projects, but only early commercial development.

Electrochromic coatings are potentially very interesting for construction because they can lead to intelligent windows and signs. They react to changes in applied voltage using a tungsten oxide layer and becoming more opaque. This means that light can be regulated, reducing energy consumption for the cooling of buildings. However, there is currently little Danish activity in this field.

Topological nanostructured surfaces is a large nano-research area in Denmark, which could be potentially interesting for construction, e.g. leading to strong surfaces (thermally stable, wearability), anti-fouling properties, selective permeability for separation processes and water-repellent construction.

3.2.3 Pillar 3. Nano-optics

3 Optics			
3.1 Optics	Applications and relevance for construction	Companies	Nano scientists
3.1.1 Planar lightwave circuits Micro and nanofabrication of optical circuits on silicon wafers.	Application focus: Optical communication Potential in construction: Fibre to the home based on planar lightwave circuits. Making optical circuits on a silicon wafer. Development stage: Early commercial	Ignis Photonix Comparative strength: Pioneering in the world.	J.M. Hvam, Nano•DTU J. Mørk, Nano•DTU
3.1.2 Photonic crystal fibers Optical fibers with a nanostructured arrangement of low refractive index material in a background material of higher refractive index	Application focus: Communication, sensor. Potential in construction: Optical fiber communication in different applications (telecommunication, entertainment, fibre lasers) Development stage: Commercial	Crystal Fibre A/S Comparative strength: Leading in the world.	A. Bjarklev, Nano•DTU T.P. Hansen, Nano•DTU
3.1.3 Light Emitting Diodes, LEDs Light emitting diodes. -Theoretical modeling of optical properties of organic and inorganic nanostructures including OLEDs, carbon nanotubes and inorganic nanowires.	Application focus: Lighting Potential in construction: Small light emitting diodes with low energy consumption compared to incandescent bulbs, no environmentally harmful substances, durability and flexible lighting system, potentially integrated in building materials. See Case 3.1. Development stage: Early commercial, with rapidly increasing performance of LED devices and expanding market globally.	RGB Lamps Louis Poulsen Lighting Lego <i>Nordlux</i> <i>Asger BC Lys</i> <i>NESA</i> Comparative strength: Innovative applications of new LEDs.	P.M. Petersen, Risoe C.D. Hansen, Risoe B. Thestrup, Risoe H. Pedersen, Risoe H.G. Rubahn, NanoSYD T.G. Pedersen, AAU
3.1.4 Integrated optical sensors Detection of optical signals (e.g. light intensity), includes often different light sources (laser), integrated lenses and circuits, optical filters and photodetectors.	Application focus: Pharmaceutical, Wood and Paper, Agricultural, Energy production Potential in construction: Integrated optical sensors in buildings, eg. for climate control.	OPDI Technologies A/S STC A/S NanoFab VELUX A/S Ibsen Photonics Kalaido	S. Hanson, Risoe C. D.-Hansen, Risoe O. Steensen, DELTA A. Kühle, DFM T.G. Pedersen, AU K. Rottwitt, Nano•DTU J.M. Hvam,

		Technology Aps Koheras A/S Stensborg ApS Lego Radiometer Comparative strength: Close to technological front.	Nano•DTU J. Mørk, Nano•DTU A. Kristensen, Nano•DTU NN, TI NN, Bioneer
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Table 3.3. Pillar three Nanooptics

The optics pillar is a narrower field, but could contribute to developing novel lighting systems in construction in the coming years. There is worldwide rapid development in LED (Light emitting diode) lamps, which are very promising because of the low energy consumption, no environmentally harmful substances, and the option of making intelligent lighting systems (changing the character or colour of the light) and integrating (small) lamps in materials. LEDs are rapidly expanding in civil works (traffic lights, signs). In Denmark research is more into applying LED technology in new ways rather than actually developing the LEDs.

New intelligent lighting systems could be developed in a combination of LEDs with smart materials such as organic molecular nanoaggregates (1.5.1) or memory polymers (1.4.3), functional surfaces [such as electrochromatic coatings] which could influence light reflection, and optical sensors (see also the next pillar). If these solutions were combined with smart windows, lighting systems in buildings could be made much more energy efficient and improve the indoor climate. See case 3.1.

3.2.4 Pillar 4. Nanosensors and electronics

4 Sensors & Electronics			
4.1 Monitoring	Applications and relevance for construction	Companies	Nano scientists
4.1.1 Biosensor Monitors the presence of bio-chemical substances. The specification is achieved via a bio-chemical reaction. The physical reading can be electrical, electro-mechanical, optical or ultrasonic. - Cellular sensor – the molecule changes its shape by binding. - In-vivo nanosensors. - Oestrogen receptors for detecting hormone-like compounds in the environment.	Application focus: Mainly medico, also food and environment. Potential in construction: Biosensors for monitoring biological parameters or organisms in the environment or in building materials. The devices are very small, sensitive and potentially cheap. Development stage: Many proof-of-principle but still few commercial products. More robust sensors for routine measurements under development.	<i>Danfoss</i> <i>Danfoss Bionics</i> <i>Chempaq</i> <i>Unisense</i> <i>Atonomics</i> <i>Vir Biosensors</i> <i>Radiometer</i> <i>Cantion</i> , <i>Sophion</i> <i>BioNano-</i> <i>Photonics</i> <i>STC</i> Comparative strength: Research medium, but many activities.	P.B. Ludwigsen, FORCE K. Almdal, Risoe L.H. Pedersen, Bioneer N.B. Larsen, Risoe A.S. Poulsen, Risoe H.G. Rubahn, NanoSYD E.V. Thomsen Nano•DTU P. Telleman, Nano•DTU A. Boisen, Nano•DTU F. Besenbacher, iNANO, AU J. Kjems, iNANO, AU N.P.Revsbech, iNANO P. Andreasen, iNANO T. Bjørnholm, NSC J. Wengel, SDU J.O. Jeppesen, SDU S.B. Petersen, AAU L.H. Christensen, TI NN, DELTA
4.1.2 Electroactive polymers Nanoscale material optimisation of shape/volume properties of responsive	Application focus: Transportation, electronics, pharmaceutical. Potential in construction: Integrated sensor and actuator applications in	Danfoss A/S Micromuscle AB VELUX A/S Comparative strength:	P.S. Larsen, Risoe

polymers.	windows, for climate control etc. Development stage: 0-5 years to market	Pioneering in Europe.	
4.1.3 MEMS, micro electro mechanical systems MEMS systems involve a mechanical response to an applied electric signal, or an electric response resulting from a mechanical deformation.	Application focus: Electronics, Sensor systems. Potential in construction: Production of sensors for e.g. indoor climate, etc. The major advantages of MEMS devices are miniaturization, multiplicity, and the ability to directly integrate the device into microelectronics. Multiplicity refers to the large number of devices and designs that can be rapidly manufactured, lowering the price per unit item, and thus cheap sensors. Development stage: Commercial production	Danfoss Grundfos Sonion Hymite Comparative strength: Research in front	E.V. Thomsen, Nano•DTU P. Telleman, Nano•DTU M.F. Hansen, Nano•DTU O. Hansen, Nano•DTU A. Kristensen, Nano•DTU NN, DELTA
4.1.4 Miniaturized systems (Lab-on-a-chip) Integrated and miniaturized systems for chemical analysis on a single chip. Measure at the nano-scale. Polymer-based fluid systems, photonics and electronics.	Application focus: Medico, food and environment. Potential in construction: Allows for decentralized, concentrated monitoring and diagnostics and thereby “early warning”. Pesticide analysis in drinking water (antibody-based), detection “lab on a chip” through quantitative, competitive micro-array immunoassay. Development stage: Mainly products within point-of-care in healthcare. Early production in food and environment.	VELUX A/S Danfoss Analytical ⁸ Grundfos Exicon SMB/MMP Novo Sophion T-Cellic Coloplast Comparative strength: Research in front.	A. Kristensen, Nano•DTU P. Telleman, Nano•DTU A. Boisen, Nano•DTU M. Dufva, Nano•DTU J. Kutter, Nano•DTU O. Geschke, Nano•DTU H. Bruus, Nano•DTU L.H. Christensen, TI
4.2 Transmission	Applications and relevance for construction	Companies	Nano scientists
4.2.1 Wireless data transmission All sensing/transmitting devices are miniaturised into chips. Monitoring of human beings health incl. wireless access to alarmcenters and support personnel. Eventually the sensors will be transplanted into humans and animals, still featuring wireless data transmission.	Application focus: General, pharmaceutical, medical. Potential in construction: Wireless data transmission from miniaturised sensors in buildings, eg. in relation to monitoring of humidity, pollution, noise and mechanical load. See Case 4.1. Development stage: 0-5 years to market.	VELUX A/S Comparative strength: Pioneering in the world.	O. Steensen, DELTA NN, COM•DTU
4.2.2 Pervasive sensing Small cheap micro- and nano-structured sensors embodied in many different types of ‘devices’ (closely linked to regulation). - Sensors based on RFID technology (tags for labelling) are expected to be largely disseminated.	Application focus: Medical, Automation Potential in construction: Cheap, wireless and without internal energy supply (battery) and disposable sensors (tags) to be incorporated in buildings materials. Potentials for intelligent dosage systems & improved process control, e.g. washing machines, tags for waste separation and monitoring materials. Development stage: Commercial production of condition and structural health monitoring is increasing strongly. The durability of some products is short.	VELUX A/S STC Danfoss Grundfos Tempress H.F. Jensen Unisense Unisensor Foss Analytics Dantec MEMSFLOW Comparative strength: New area	
4.2.3 Polymer-based electronics	Application focus: Electronics Potential in construction: Smart integrated electronic/communication functions in	Capres Atomistix SMB/MMP	M.M. Nielsen, NSC F.C. Krebs, Risoe K. Rottwitt, Nano•DTU T. P. Hansen, Nano•DTU

⁸ Danfoss Analytical has been sold to HACH LANGE in 2005/2006

Polymer-based electronics with less use of materials and often less energy consumption: - TFT flat screen. - Local Area Networks (LAN). - Molecular computing. - RFID devices, based on polymer field effect transistors.	buildings and building components. -RFID, see also “Pervasive sensing” above Development stage: Polymer electronics is beginning to be developed commercially; currently, products are too unstable. Many applications expected in a long-term horizon. Specific photonic applications are moving into development stage.	<i>BioNanoPhotonics</i> Comparative strength: Early stage, for the time being a minor role.	<i>T. Bjørnholm, NSC</i> <i>J.O. Jeppesen, SDU</i>
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Table 3.4. Pillar four Sensors & Electronics

The sensors and electronics pillar is another large Danish nanoscience area with quite a lot of companies involved. The application focus today, however, is primarily medicine or food, but it could easily include construction. The area is not least relevant for indoor climate monitoring and control (air quality, pollution, noise), but also for monitoring the mechanical load and for making overall smart buildings.

E.g. electroactive polymers could be used as integrated sensors and actuators in windows and for indoor climate control. The miniaturised systems could be used for integrated, chemical analysis of e.g. pollutants on a single chip. Pervasive sensing though RFID technology is a rising market where small integrated tags allow for e.g. intelligent dosage systems (demand driven) & improved process control, e.g. washing machines, tags for waste separation (recycling).

Combining the sensors with *wireless data transmission* could lead to smart buildings, See also case 4.1. And *polymer electronics*, a new promising area in early commercial development, could more fundamentally contribute to smart integrated electronic/communication functions in buildings and building components.

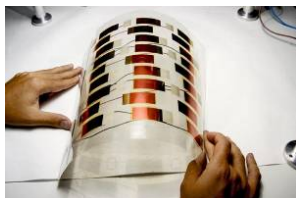
3.2.5 Pillar 5. Integrated energy production and distribution

5 Integrated energy production and distribution			
5.1 Fuel-cells	Applications and relevance for construction	Companies	Nano scientists
5.1.1 Hydrogen storage and fuel cells Nanoporous materials (metal hydrides). - Nanostructured materials for electrodes. - Synthesis of complex metal hydrides promising for H ₂ storage and thus hydrogen fuel and nanoporous organic networks.	Application focus: Energy supply, transportation, chemical. Potential in construction: New nanomaterials for hydrogen storage for fuel cells and integrated energy production in buildings. - Hydrogen production. - Hydrogen storage in nanoporous materials (metal hydrides). -Cheap materials for electrodes (nano-structured).	Amminex A/S Topsoe Fuel Cell IRD Fuelcells Danfoss A/S Dantherm A/S	T.R.Jensen, iNANO, AU T. Vegge, Risoe N. Bjerre, DTU J.K. Nørskov, Nano•DTU I. Chorkendorff, Nano•DTU J. Rossmeisl, Nano•DTU C.H. Christensen, Nano•DTU M. Mogensen, Risoe S. Linderorth, Risoe

	Development stage: Early development.	Comparative strength: New area.	R. Feidenhans'l, NSC F. Besenbacher, iNANO, AU B.B.Iversen, iNANO AU J.E. Jørgensen, iNANO AU
5.2. Solar Cells	Applications and relevance for construction	Companies	Nano scientists
5.2.1 Polymer based solar cells Nanostructuring of the binary blends important for performance.	Application focus: Energy production, transportation Potential for construction: Very cheap solar cells printed on thin plastic films, potential for wide distribution of solar cells, e.g. integrated in buildings materials and components, curtains ect. See Case 5.1. Development stage: Experimental, short durability, first products expected soon.	Mekoprint, SP systems, Konarka, SEAS, VITEX Comparative strength: New area, among pioneers.	F.C. Krebs, Risoe
5.2.2 Hybrid solar cells Nanostructure obtained through the use of inorganic nanoparticles, nonporous structures or nanorods.	Application focus: Energy production, transportation. Potential for construction: Low cost combination of inorganic and organic semiconductors. Flexible and printable. Development stage: Experimental, poor stability.	Konarka, SCM, G24i, Vivesa Comparative strength: New area.	F.C. Krebs, Risoe
5.2.3 Extremely thin absorber solar cells, ETA Nanostructure obtained through nanoporous networks or nanorods.	Application focus: Energy production Potential for construction: Extremely thin absorber film solar cells potentially integrated into building materials. Development stage: Research stage. 10-15 years to market	Comparative strength: New area.	M. Biancardo, Risoe F.C. Krebs, Risoe
5.2.4 Dye sensitized solar cells Solar cells printed or coated on semi-flexible titanium foils, films or encapsulated in glass. Mostly sintered nanoporous materials based obtained from sol-gel processes.	Application focus: Energy production. Potential for construction: Cheap solar cells to be integrated in building materials e.g. windows. Development stage: Commercial, companies delivering production machinery, companies with 25 MW production capacity established.	Konarka, SCM, G24i Comparative strength: New area.	M. Biancardo, Risoe F.C. Krebs, Risoe NN, TI
5.3 Other	Applications and relevance for construction	Companies	Nano scientists
5.3.1 Superconducting materials Improving the critical current of a superconductor by introducing impurities, this has a size matching the coherence length of the superconductor(the order 5-50 nm) - incorporating nanoparticles into clean superconductors.	Application focus: General, medical, energy production. Potential for construction: Integration of conducting materials in building materials for integrated energy production and wires. Development stage: 5-10 years to market.	Danfysik A/S American Superconductors Inc. Sumitomo Electrics Comparative strength: Pioneering in Denmark.	A.B. Abrahamsen, Risoe J.C. Grivel, Risoe
5.3.2 CO2 fixation and liquid fuel production CO2 fixation: Fixing CO2 directly from the atmosphere for use in syn-gas production and methanol production Catalytic systems: Systems for reducing CO2 to liquid fuel. Mainly as methanol but formic acid is also possible	Application focus: General, energy production. Potential for construction: -CO2 fixation and catalytic systems Sunlight is used for the efficient and carbon emission free assimilation of CO2. -Catalytic systems produce syngas and methanol for storage of methane for the natural gas net. This can be done on both a large centralized scale and on a decentralized scale i.e. providing carbon emission free heating and electricity for housing and fuel for private	Dong Energy Haldor Topsøe A/S Comparative strength: New area.	F.C. Krebs, Risoe C.H. Christensen, Nano•DTU T. Bligaard, Nano•DTU

	transport. See Case 5.2. Development Stage: Research		
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Table 3.5. Pillar 5 Integrated energy production and distribution



Organic Solarcells,
Frederik Krebs, Risø.
Photographer: Gitte Sofie
Hansen.

Pillar 5 focuses on nano-related energy production integrated in buildings, i.e. decentralised energy supply and storage. Energy production is a high priority area in Danish nanoscience⁹. The production and storage of hydrogen is a new but fairly large research area which builds on the strong Danish competencies in catalysis. But worldwide this is an area in early commercial development. Micro fuel cell plants could potentially be used for clean energy production in buildings.

The other main area is solar cell energy, in which some of the upcoming methods are nanotechnology-based. In Denmark there is pioneering research on four different kinds of such solar cells. The common denominator is that they are very cheap and very thin, and potentially can be built into or coated on products, e.g. curtains, roofs, windows, etc. Most of these products are pre-commercial, but showing rapid progress in their development. The exception is *dye-sensitised solar cells* which are already commercially available [but with no Danish companies involved.]

The *superconducting materials* could be integrated in building materials and used for improving the distribution of energy in buildings.

3.2.6 Pillar 6. Integrated environmental remediation

6 Integrated environmental remediation			
6.1 Catalytic cleaning	Applications and relevance for construction	Companies	Nano scientists
6.1.1 Crystalline nanoporous materials High surface area material that serves as a catalyst support or substrate, and the surface linings of its pores contain a dispersed active component which bring about or accelerate a catalytic reaction for e.g. gas cleaning. - heterogen catalysis	Application focus: General, Chemicals, Environmental (gas cleaning in refineries, trucks), construction. Potential for construction: Construction materials with integrated catalytic properties for improvement of the indoor climate (removal of volatile pollutants). Development stage: Fully commercial heterogen catalysis, 0-5 years to market in construction.	Haldor Topsøe A/S VELUX A/S Comparative strength: Pioneering in the world.	J. Skibsted, iNANO, AU T. Bligaard, Nano•DTU, H.C.B. Hansen, Faculty of Life Sciences, CU C.B. Koch, Faculty of Life Sciences, CU T.R. Jensen, iNANO, AAU I. Chorkendorff, Nano•DTU,
6.1.2 Metal oxides and hydroxides	Application focus: General, environmental. Potential for construction:		H.C.B. Hansen, Faculty of Life

⁹ Especially at Nano.DTU, Risø and iNANO.

Engineered metal oxides and hydroxides, in particular layered double metal hydroxides (LDHs).	Catalytic degradation processes in waste water cleaning, soil and groundwater remediation. Development stage: Research idea	Comparative strength: New area	Sciences, CU C.B. Koch, Faculty of Life Sciences, CU
6.1.3 Photocatalytic degradation Method based on oxidation by uv-light transforming unwanted chemical substances into “innocent” compounds. Photocatalytic degradation in water.	Application focus: Environmental Potential for construction: Water cleaning, e.g. removal of organic pollutants in water. Development of new innovative materials that can clean the air from unwanted pollutants. See Case 6.1. Development stage: 0-5 years to market.	Maxit Aquaporin Aps Comparative strength: Pioneering in Denmark.	M.M. Klausen, DHI N. Knudsen, SBI, AAU P. Wargocki, MEK, DTU
6.2 Other separation/cleaning processes	Applications and relevance for construction	Companies	Nano scientists
6.2.1 Membrane process Membrane filtration. With ultrashort laser pulses, one can make membranes with nanopores in any material, including polymers and metals. - Combination of membrane and fermentation processes. - Bioactive polymer membranes.	Application focus: Environmental Potential for construction: Bioseparation and production of sensor components. Water cleaning with photocatalytic degradation and membrane filtration. Development stage: Used for gas cleaning mainly. 5-10 years to market.	Aquaporin Aps <i>Versamatrix</i> <i>JURAG</i> <i>Alfa Laval</i> <i>Danisco</i> Comparative strength: New area.	M.M. Klausen, DHI B.B. Iversen, iNANO, AU C.H. Christensen, Nano•DTU M. Foss, iNANO, AU P. Kingshott, iNANO, AU P.V. Petersen, Risoe G. Jonsson, Nano•DTU M.E. Vigild, Nano•DTU
6.2.2 Electrochemical cleaning of gases Efficient cleaning method where electricity substitutes chemistry, (know-how from fuel cells).	Application focus: Environmental. Potential for construction: cleaning of gases, indoor climate? Development stage: Experimental, patent submitted.	<i>Dinex</i> <i>Volvo</i> Comparative strength: Unique research.	M. Mogensen, Risoe K.K. Hansen, Risoe J. Rossmeisl, Nano•DTU
6.2.3 Electrochemical treatment of solid materials for cement based materials - Electrochemical pre-treatment of fly ashes otherwise identified as waste. - Electrochemical removal of chloride from concrete.	Application focus: Environmental. Potential for construction: Reuse of treated fly ashes in cement based materials as a substitute for coal fly ash (waste reduction by reuse of fly ash otherwise disposed by landfilling). New method for removal of chloride from concrete. See Case 1.7 and 1.8. Development stage:?	 Comparative strength: ?	L. Ottesen, BYG•DTU I.V. Christensen, BYG•DTU
6.2.4 Molecular sieving Nanoporous materials that act as a molecular sieve suitable for filtering out molecules of particular sizes, has a controlled narrow range of pore diameters.	Application focus: ? Potential for construction: cleaning processes of air, in waste water cleaning, soil and groundwater remediation. Development stage:?	 Comparative strength: ?	N. Knudsen, SBI, AAU P. Wargocki, MEK, DTU J. Skibsted, iNANO, AU T.R. Jensen, iNANO AU C.B. Hansen, Faculty of Life Sciences, CU C.B. Koch, Faculty of Life Sciences, CU M.E. Vigild, Nano•DTU
6.2.5 Sorption Sorption is the process in which one substance takes up or holds another by either absorption or adsorption. Development of engineered metal oxides and hydroxides, in particular layered double metal hydroxides (LDHs). - New nanomaterials with sorption	Application focus: Environmental Potential for construction: - Sorption and catalytic degradation processes in waste water cleaning, soil and groundwater remediation. - New air-cleaning building materials leading to more healthy and energy efficient buildings (less energy needed for ventilation).		N. Knudsen, SBI, AAU P. Wargocki, MEK, DTU C.B. Hansen, Faculty of Life Sciences, CU C.B. Koch, Faculty of Life Sciences, CU

properties can be integrated in building materials e.g aircleaning nanocrystals integrated in construction surfaces.	Development stage: Research	Comparative strength: ?	
6.2.6 Colloidal chemical tools	Application focus: Industrial separation/cleaning processes. Potential for construction: Development of tools for analysis and control of industrial production systems to facilitate optimisation of production processes. Development stage: ?	Brdr. Hartmann Comparative strength: ?	M.M. Klausen, DHI NN, TI
6.2.7 Remediation with nanoparticles Decontamination by reaction with functional nano particles or thin films - either using synthetic material or modified minerals. –catalytic Combined with sensors in e.g. the soil. Biological adhesion to natural materials and implications for degradation-sorption. "Natural attenuation": exploit the natural cleaning capacity of nanosize (clay and other minerals) particles in the soil-sorption.	Application focus: In soil and water, water treatment facilities, waste treatment plants and storage areas, flue gas and fly ash treatment, nuclear waste repositories ect. Immobilization and breakdown of pollutants. Development stage: Various – some projects improve existing commercial technology, others study the fundamental properties to develop new approaches.	<i>Hedeselskabet SKB - Svensk Kärnbränslehantering</i> Comparative strength: Some projects are state-of-the-art, leading on international fronts.	D. Plackett, Risoe S. Stipp, NSC H.C. B. Hansen, Faculty of Life Sciences, CU C.B. Koch, Faculty of Life Sciences, CU K.J. Jørgensen, Faculty of Life Sciences, CU H. Lindgreen, GEUS C.S. Jacobsen, GEUS, F. Larsen, DTU T. Christensen, DTU A. Bennow, Faculty of Life Sciences, CU
6.2.8 Nanoparticles formed into meshes, wires or colloid 3D constructs.	Application focus: medico (transport & penetration, increase surface area). Potential for construction: Wide application potential, e.g. as scavengers of pollutants, flocculation. Development stage: Experimental.	Comparative strength: Among early pioneers.	S. Ndoni, Risoe M.E. Vigild, Nano•DTU P. Kingshott, iNANO, AU K. West, NSC T. Bjørnholm, NSC B.L. Møller, Faculty of Life Sciences, CU
6.2.9 Active particle deposition surfaces Active surfaces with increased particle deposition properties.	Application focus: Potential for construction: Improved indoor air quality: Production of active surfaces in buildings which may increase deposition of fine and ultrafine airborne particles onto the surface. See Case 2.2. Development stage: ?	Comparative strength: ?	A. Afshari, SBI, AAU
6.3 Risk assessment	Applications and relevance for construction	Companies	Nano scientists
6.3.1 Risk assessment of nanomaterials - Development of risk assessment procedures for nanomaterials in the environment. (conceptual frameworks, laboratory research on side-effects of nanomaterials released into the environment.	Application focus: Safety and risk assessment of nanoparticles. Potential for construction: Risk and environmental assessments of new nanotechnologies to be used in construction. Development stage: New area globally.	Comparative strength: New area.	A. Baun, Nano•DTU S.I. Olsen, Nano•DTU H. C. B. Hansen, Faculty of Life Sciences, CU NN, DHI

Table 3.6. Pillar 6 Integrated environmental remediation

Pillar six focuses on nano-related environmental remediation in buildings or local areas, i.e. decentralised environmental solutions both for improving the external environment as well as indoor climate. These solutions could also be used in civil engineering (water supply and sewage systems) as well as in special buildings with heavy local environmental loads or odours, such as stables, manure containers, etc. As should be clear from the mapping analysis so far, many of the

nanotechnologies described so far have direct or indirect positive environmental impacts, but the areas mentioned in this pillar specifically aim at environmental remediation.

The area is quite large, with in all 14 sub-areas, but it is generally more science-based while industrial activity is somewhat limited (see also Andersen and Rasmussen, 2006, Andersen 2007, for a closer discussion on Danish eco-opportunities and risks from nanotechnology). Many of the areas represent novel upcoming solutions to environmental remediation.

The catalytic cleaning group builds on the world-leading catalysis competencies in Denmark. However, the similarly world-leading company Haldor Topsoe's activities are mainly directed at large-scale catalytic cleaning in refineries, rather than decentralised solutions (though they have recently diversified into trucks). Nonetheless, there is a very strong science and industry base to build on in this area also of relevance for more decentralised solutions. Of particular relevance to construction are the *crystalline nanoporous materials*, which have integrated catalytic properties which could improve the indoor climate by removing volatile pollutants. Furthermore this is a Danish stronghold in early commercial development.

Photocatalytic cleaning is a new area for the degradation of organic pollutants in water. Similarly engineered *metal oxides and hydroxides* are used for effective catalytic degradation processes and sorption in waste water cleaning, soil and groundwater remediation.

Other cleaning methods are e.g. effective *membranes* with nanopores and *molecular sieving*, where nanoporous materials act as a molecular sieve. *Electrochemical cleaning* is used both for gas cleaning (indoor climate), for pre-treatment of flyashes, so it can be used in cement for the removal of chloride, thereby reducing the waste problems with cement-based materials. Electrochemical cleaning is also used for treatment of soil and wood products.

New layered double metal hydroxides (LDH) nanomaterials with *sorption* properties (e.g air-cleaning nanocrystals) can be integrated in building materials improving the indoor climate and reducing the need for ventilation (energy efficiency). *Remediation with nanoparticles* entails the use of nanoparticles for the immobilisation and breakdown of various pollutants. Production of *active particle deposition surfaces* in buildings may increase deposition of fine and ultrafine airborne particles on the surface thereby improving the indoor air quality.

Finally, the development of risk and environmental assessment procedures for nanomaterials is essential for developing safe and responsible nanotechnology, and addressing possible risk issues in time, not least when it comes to indoor applications for nanomaterials (see also the policy section on environmental policy as well as the appendix 4 on risk aspects).

3.2.7 General nanoscience and technology development

Finally, and not really a pillar, there is a group of nanosciences which are of a more fundamental and general nature such as nanomanufacturing techniques, which in important ways feed into the other nanoactivities.

Techniques and competencies			
	Applications and relevance for construction	Companies	
<p>nanoparticles</p> <p>critical oxides, for much faster synthesis of</p>	<p>Application focus: General, (fuel cells, solar cells, catalyst supports, electronics etc.).</p> <p>Potential in construction: Improvement of size/distribution and price may create a burst in commercial exploitation, e.g. for functional surfaces.</p> <p>Development stage: Commercial stage.</p>	<p>SCF Technologies</p> <p><i>Grundfos</i></p> <p>Comparative strength: New research and production area with unique production facility</p>	<p>B A T A J. in H A C N C N</p>
<p>nanotubes</p> <p>Characterization of (carbon Ni</p>	<p>Application focus: General.</p> <p>Potential in construction: In nanocomposites for building materials etc.</p> <p>Development stage: ?</p>	<p>Comparative strength:</p>	<p>R A</p>
	Applications and relevance for construction	Companies	
<p>nanoparticles</p> <p>production of products, ceramics</p>	<p>Application focus: General.</p> <p>Potential in construction: Many applications: for construction surfaces, mechanical devices (MEMS, sensors), etc.</p> <p>Development stage: Commercial use of some techniques</p>	<p>Danfoss</p> <p>Grundfos</p> <p>Sonion</p> <p>Noliac</p> <p>B&O</p> <p>Pinol</p> <p>Coloplast</p> <p>Novo Nordisk</p> <p>Comparative strength: In front</p>	<p>H N P N O N</p>
	Applications and relevance for construction	Companies	
<p>nanoparticles</p> <p>Micro-angle Magnetic Resonance Tomography of</p>	<p>Application focus: General, construction</p> <p>Potential in construction: The technique enables investigation of both crystalline and amorphous phases in cementitious systems and can extract information about chemical composition, hydrational reactivities and local structural environments. Structures down to the atomic level can be observed. Core project is Hydration of blended cements.</p> <p>Development stage: ?</p>	<p>Aalborg Portland A/S</p> <p>Comparative strength: ?</p>	<p>S in T in</p>
<p>nanoparticles</p> <p>scale X-ray</p>	<p>Application focus: General.</p> <p>Potential in construction: Encompasses nanoscale structural control, both in bulk and on surfaces (catalysts, self-assembled organic electronics, cement, natural materials, e.g. chalk). See Case 7.1.</p> <p>Development stage: ?</p>	<p>Comparative strength: Research in front</p>	<p>J. R M</p>

Table 3.7. General nanoresearch

3.2.8 General discussion on the supply of nanotechnology for construction

While Danish nanoscientists and nano-dedicated companies generally are very competent and in many areas do research at international levels, they are currently only in a limited way involved in or oriented towards the construction sector. In fact in some cases we have experienced a disinterest in the (low-tech) construction sector (influencing the participation in our mapping and workshop, in which some institutes did not participate) and clearly lacking any insight into the needs of the construction sector. This may possibly also illustrate the fact that it is a new exercise for the nanoscientists (and the nano-centres) to consider the needs of a specific sector, because such an approach has not been carried out in Denmark before. And many nanoscientists still have a weak industrial orientation.

Most of the nano-active companies in construction are in the field of building materials and components. They represent key actors in dissemination of nanotech information as well as representing the supply-side of the market. Their numbers are not very substantial yet though. They are currently in a decisive strategic phase for nanotechnology. They are attentive to nanotechnology, but in the early stages in relation to their strategy and may be only just entering R&D activity in the field. Strategies are not yet decided, so they hesitate to reveal them. In other cases, they are involved in nano-related innovation or moving into new markets which they are also unwilling to reveal. Examples of such companies are Danfoss, BASF, DK Construction, Maxit, SCF Technologies, Icopal, Rockwool, Velux and Velfac. A new trend is that they are increasingly interested in pulling in the nano-expertise in their foreign mother Group (when they have one), and considerations about the use of this expertise are at an early stage, see the cases 2.4 and 6.1. The exception is the nano-concrete area, which is more mature, see the case 1.1. Apart from this the supply side is made up of nano-dedicated companies that have not yet oriented towards construction, but with potential interests in this area, such as Nanon and Haldor Topsoe.

For new players in nanotechnology in particular, the protection of intellectual property rights is a key issue. They have little interest in stimulating other firms to engage in nanotechnology. On the other hand, nanotechnology is an area that is well-protected with patents and thus clear property rights.

3.3 The demand and views on nanotechnology in the construction sector

This section gives a short overview of the demand for, expectations about and knowledge of nanotechnology in the Danish construction industry for those many companies and other construction actors who are currently not very active or knowledgeable about nanotechnology. We also look at the perceived barriers to nano-construction. The input comes from an interview round among respectively architects, contractors, producers of materials and components, facility managers,



Dorte Mandrup Arkitekter.
Kvarterhus Jemtelandsgade,
eksteriør. Photographer: Jens
Markus Lindhe



Dorte Mandrup Arkitekter.
Kvarterhus Jemtelandsgade,
interiør. Photographer: Jens
Markus Lindhe

as well as from cases, and the NanoByg workshop and survey¹⁰. The material and component producers were covered in the previous section.

Initially we will summarize the demands and problems of the construction sector. The table below was inspired by the Strategic Research Agenda¹¹ (SRA) of the ECTP, the Danish ECTP¹² focus areas and Vision 2020¹³. These documents were created in a dialogue between different actors of the construction sector and academic researchers, so they give a good illustration of the demands and problems that concern the industry today. The demands and problem table of the construction industry has a considerable overlap with the tables of the last section, which thus show a great potential for nanoconstruction. It is also possible to find areas where the construction industry, or at least the writers of these policy documents, shows a fairly good knowledge of nanotechnology in that they can formulate their demands and functionalities with inspiration from nanotechnology and research.

However, there are also social and managerial challenges, which brings to the fore the intricate relation between technology and management for the vitality of an industry. Both ECTP (European and Danish) and Vision 2020 argue for a strengthening of innovation in the construction industry. The construction industry has realized some of its own structural problems, the question is if they are willing and able to take on the challenges? These documents show at least an engagement at the policy level by some of the key player in the industry.

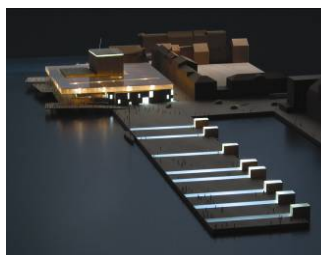
Focus area	Demand/functionality
Energy, indoor climate and ventilation	Cleaner air, less odour, less particles
	Catalytic cleaning of air
	Less waste of heat in ventilation
	Self cleaning and easy to clean surfaces
	Killing organic materials, e.g. fungus
	Energy storage
Materials	CO2 neutral
	Low-energy houses
	Insulation
	Development of intelligent measure and control systems
	Nano-, sensor- and information technology introduced in building materials
	Active and multifunctional materials: reacts on moist, sunlight or dirt.
	Changing shape and functionality
	Aesthetic durability and quality of materials
	Stronger, stiffer, tougher and more thermal stable materials
	Higher freedom for construction, design and architecture
	Better ratio between strength and weight

¹⁰ Seven architects and 9 entrepreneurs and other construction people have been interviewed during January 2007.

¹¹ http://www.ectp.org/documentation/ECTP-SRA-2005_12_23.pdf

¹² <http://www.ectp-denmark.dk>

¹³ http://www.ebst.dk/file/3887/vision2020_byggeri_med_mening.pdf



Lundgaard & Tranberg
Det Ny Skuespilhus.
Under construction.
Model photo: Ole Akhøj



Lundgaard & Tranberg
Det Ny Skuespilhus.
Under construction.
Model photo: Ole Akhøj



Lundgaard & Tranberg
Det Ny Skuespilhus.
Under construction.
Rendering: Lundgaard & Tranberg

	Better resistance to moist and dirt UV resistance
Building production	Less waste
	Industrialization Globalization
	Broader and less rigid craftsmanship Education
	Better work environment and health in the building process
	Sustainable management of transport and utilities networks
	A new client-driven, knowledge-based construction process
	More Innovation More alliances with companies in other industries More focus on system integrators Introducing knowledge brokering

Table 3.8. Demands and problems of the construction industry.

3.3.1 The demand, expectations and views on nano-construction as perceived by the Danish construction sector

Looking at the demand side of nanotechnology-based solutions, it is clear that the construction sector is reluctant about the use of nanotechnology. Most of all, the demand side is hampered by a lack of knowledge of the potential of nanotech – and by an element of uncertainty in relation to nanoparticles and health risks.

Clients

Clients are central for decisions in construction. They are the buyers – and are the ones who express needs, choose suggested solutions, and finance the whole project. Because of this central position, the Public Clients in particular have a special position in Denmark, as a key agent for development in construction.

Our findings show a clear picture. The clients, e.g. the Ministry of Transport and Energy, are mostly unaware of nanotechnology. They are heavily dependent on advice and suggestions from architects, and – increasingly – facility managers and consultants.

Architects

Architects are potentially key agents of change in relation to the introduction of new materials and new technological solutions in the construction industry. Not only are they important in relation to the material choices in the design phase, but they may also be a vehicle for the formulation of more radical visions and innovations as the case on Memory Rich Walls suggests, see case 1.8. Danish architects represent an international outlook in the industry, as some offices are involved in projects in locations such as the Middle East and China.¹⁴

¹⁴ E.g. Henning Larsens Tegnestue is an international office with many projects abroad especially in Dubai and the Middle East. In these extreme climates nanotechnologies and smart materials could be used for the control of heat gain and natural ventilation as well as solar energy.



3XNielsen, Ørestad Gymnasium,
2007, København.
Photographer: Adam Mørk



3XNielsen, Ørestad Gymnasium,
2007, København.
Photographer: Adam Mørk



3XNielsen, Ørestad Gymnasium,
2007, København.
Photographer: Adam Mørk

Our analysis has shown that architects are still having difficulties in defining themselves in relation to nanotechnology. Accordingly, none of the architectural offices replied to the survey sent out in November 2006. Despite this, their interest in nanotechnology seems considerable. Thus, architect participation in the NanoByg workshop was very high, and interest in the formation of an architect network on nano-construction has already been expressed as a result of the workshop, the argument being that architects (for once) ought to take a proactive stance and forward this new technology¹⁵.

“Nanotechnology is a new field in need of testing and trials and which is not accessible to architects. It also requires that architects put pressure on the other construction partners and that a new consciousness among building producers is created.” - Kasper Guldager Jørgensen, 3XN, architectural office.

Interest in nanotechnology is present in both the smaller and the leading architectural offices in Denmark. But if we look at the capacity and ability to implement new technology, the larger companies have an advantage. Architects show a special interest in coatings, because they seem readily available, but also new materials.

“We believe that plastic composites are a state-of-the-art building material with enormous potential – not least because plastic composites enable the creation of integrated design, allowing elements such as cables, lighting, reflectors, water, etc., to be built into the actual composite modules. We are currently working on developing these perspectives.”
- Nille Juul-Sørensen. KHR A/S, architectural office.

“Nanotechnology does not exist in the consciousness of architects. We know the word but not its specific application or its economics. There is a need to identify the technology and its added value – and its relation to existing materials. We need a more ‘straightforward’ approach and knowledge of the implementation options.” - David Zahle, Plot, architectural office.

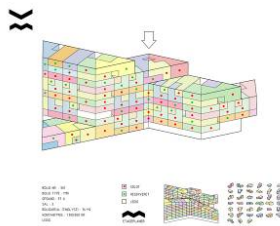
¹⁵ According to Henrik Mørk, architect, ERIK MØLLER ARKITEKTER, and participant at the NanoByg workshop and initiator of a possible NanoByg architect network. The workshop he designated and “eyeopener” on the new nanotechnological opportunities.



PLOT=B.I.G+JDS, VM-Husene, Ørestaden.
Photographer: Johan Fowelin



PLOT=B.I.G+JDS, VM-Husene, Ørestaden.
Photographer: Nicolai Möller



PLOT=B.I.G+JDS, VM-Husene, Ørestaden. Diagram



PLOT=B.I.G+JDS, VM-Husene, Ørestaden
Photographer: Stuart McIntyre

One barrier identified by the architectural offices interviewed is the expectation that nanomaterial costs will be too high. This argument was specific in relation to nano-coated glass, where the real cost is multiplied by a factor of ten. This argument can probably be framed in a more general sense as reluctance by clients and contractors to accept new technological solutions and materials if prices and risks are perceived as high. Another barrier which maintains the use of traditional materials is regulatory standards.

However, in this formative phase of a nanotechnological trajectory within the construction industry, the lack of knowledge and collaboration between architects and other parties seems to be a very important barrier. Such collaboration could be a driving force for more radical visions on nanotech in construction in contrast to the present lack of coordination, and architectural expertise should be included, was the view expressed in the NanoByg workshop.

“We could use somebody to gather knowledge, experience and documentation, such as a trade organisation or a uniting agency to provide and communicate information”.

- Lundgaard & Tranberg, architectural office

So the overall picture is that interest and motivation is high, while knowledge is low.

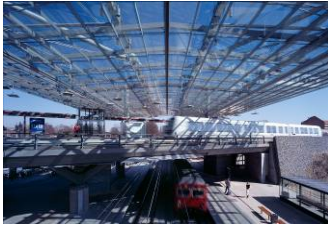
The contractors and consulting engineering companies

Some of the leading Danish contractors and consulting engineering companies were contacted to obtain their views on nanotechnology and on their role in the introduction and diffusion of new materials and technologies. All of the companies were supportive of the NanoByg idea, and showed considerable interest in nanotech as a technological field with radical change potentials.

“New solutions often use concepts like the environment and security as arguments. Nanotechnology opens up the possibility of thinking more "aggressively" about solutions and options. For it is certain that one day nanotechnology will become part of the everyday life of Danish workers... some time in the future” - Arne Gotfredsen, CEG, Danish contractor

“I think that it is in the application side that Danish construction companies have a potential. Combining nanotech with existing technology is an area of opportunity in contrast to basic research”. - Rolf Carlsen, Pihl og Søn, Danish contractor

But the contractors do not see themselves as central agents of change in relation to the development and diffusion of new nanomaterials and technologies, and concrete knowledge of nanotech applications in construction was limited.



KHR, Flintholm Station.
Photographer: Adam Mørk



KHR, Flintholm Station.
Photographer: Adam Mørk



KHR, Flintholm Station.
Photographer: Adam Mørk

Knowledge of new materials is primarily obtained from manufacturers. In most cases materials, are decided by the client/architect, but in some cases the contractors also have a say. Another reason why contractors may be reluctant to use new materials is that they bear the main risk if the material does not perform. Some contractors express concern about health risks related to nanoparticles, particularly in the work place.

“We are practitioners and work with the tools and materials known today. As nanotechnology one day becomes more used, we will gain more knowledge of it as a matter of course”.

- NN, CEG, a Danish contractor

The consultants have a key function in relation to advising clients – as well as contractors. But the knowledge about nanotechnology is very limited. E.g. Rambøll, a major Danish consulting engineering company, calls for better guidance on surface-coating products.

Facility managers

Facility management has increasing importance for the development of the building environment – not only in relation to the managing and operation of energy, climate, ventilation factors, but also in relation to decisions about how requirements for space can be met by renewal or new builds. Facility managers receive information about new technology from consultants – and from the producers and suppliers of materials and components. The interviews show that facility managers are unaware of nanotechnologies. They tend to be hesitant about using nanotechnology and are awaiting documentation on the benefits – in terms of both functionality and economy, and in the short-term as well as the long-term.

Conclusions on demand

The overall picture on the demand for, knowledge of, and views on nanotechnology in the construction sector is that knowledge and expertise are currently too fragmented to allow for a substantial uptake, diffusion and development of nanotechnological solutions in the construction industry. At present, only very vague ideas of the possible benefits can be identified among key agents of change such as architects, consulting engineers and facility managers. Furthermore the demand side will be reluctant about introducing nanotechnological materials until convincing documentation about functionalities and long-term effects is produced. A need for documentation of the consequences for health and safety is evident.

There are substantial differences in the level of interest and motivation about nanotechnology. While contractors seem to rely on information from suppliers (we'll get the information eventually), architects seems much more interested in pursuing a defining role toward the new technological possibilities. Facility managers do not seem very aware of the possibilities of nanotechnology, though potential impacts seem considerable.

3.4 Summing up

Table 3.9. below gives an overview of Danish nano-research and technology areas and their construction relevance identified during the NanoByg pre-project.

Nano-related research and technology areas	Relevance for the construction sector (main topics)	
	Application in	Important Properties or Functions:
1. Nanostructured materials 1) Composites 2) Wood 3) Nanoporous materials 4) Polymers 5) Other materials	Insulation materials, Load carrying materials, Interior construction materials, Exterior construction materials, Surfaces	Strength, Lightness, Durability Production and execution Indoor climate Maintenance Energy efficiency Resource efficiency Recyclability Degradability Fire protection
2. Functional Surfaces 1) Chemically modified surfaces 2) Physically modified surfaces	Building surfaces, Water systems, Coating of load carrying materials, Ventilation, Heating Electrical, Lighting, Sensors, Integrated functions	Durability, Cleaning, Hygiene, Maintenance, Strength
3. Optics 1) Planar lightwave circuits 2) Photonic crystal fibers 3) Light emitting diodes, LED 4) Integrated optical sensors	Sensors, Integrated functions, Electrical and lighting systems, Fibre cables	Energy efficiency, Climate control, Fire and other safety, Cleaning
4. Sensors & Electronics 1) Monitoring 2) Transmission	Biosensors, Optical sensors, Chemical sensors, Micromechanical sensors, Microorganism sensors, Electroactive materials, Water systems	Monitoring and control, Integrated functions in electrical and lighting systems
5. Integrated energy production and distribution/storage 1) Fuel cells 2) Solar cells 3) Other	Solar cells, Hydrogen storage, Fuel cells, Exterior materials, Ventilation, Heating	Energy efficiency and self-sufficiency, Resource efficiency, Indoor climate
6. Integrated environmental control and 1) Catalytic cleaning 2) Other separation/cleaning processes 3) Risk assessment	Water systems (supply and waste), Catalysis, Separation processes, Waste systems	Cleaning and hygiene, Indoor climate, Integrated functions, Degradability, Resource efficiency, Energy efficiency Substitution of Hazardous materials, Production and execution,
General nano-research and competences 1) Synthesis 2) Manufacturing 3) Characterisation	Fundamental material understanding and design	

Table 3.9. Overview - nano-related areas and their relevance for the construction sector.

The overview illustrates the great variety and scope of nanotechnology, the many emerging technological areas, and the broad application opportunities which address almost all aspects of construction.

Further work is needed to clarify in more depth how nanotechnologies may remedy specific problems and requirements of the construction sector, e.g. indoor climate, fire and risk protection, energy efficiency, lighting systems, efficient production methods, waste handling, etc. The overview shows that nanotechnology potentially may offer many novel solutions in Danish construction, and improve many properties both in relation to improving production processes, materials and components for newbuilds, and renovation of existing buildings, as well as influencing the uses, living conditions, and disposal of buildings and civil works. Not least, energy and environmental opportunities seem to be considerable.

However, many of the novel solutions are in an early stage of development, although others are fully commercial. In most cases, further development is needed to help the many identified science and technology areas address the specific problems and conditions of the construction sector.



3XN, Musikhuset, Amsterdam.
Exterior. 2005.
Photographer: Adam Mørk



3XN, Musikhuset, Amsterdam.
Exterior. 2005.
Photographer: Adam Mørk



3XN, Musikhuset, Amsterdam.
Exterior. 2005.
Photographer: Adam Mørk

4 Positioning NanoByg

The aim of this chapter is to present the institutions and players already active in nano-construction, but also players who are potentially relevant because they could complement, collaborate with, or take part in a possible NanoByg initiative. Most emphasis is placed on knowledge institutions and networks in this discussion, particularly those involved in high-tech R&D activities. Key industrial players have been covered in the previous mapping chapter.

4.1 Actors and institutions in construction

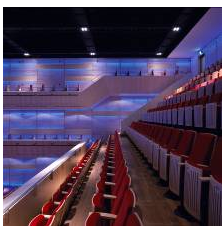
4.1.1 Danish actors and institutions in construction

Knowledge institutions traditionally involved in the development of the construction sector consist of universities, former government research institutes, and GTS institutes (Approved Technological Service institutes). Key actors are BYG•DTU, the Danish Building Research Institute (SBI – Aalborg University) and the GTS institutes, Danish Technological Institute (DTI) and FORCE technology. Relevant activities involve directions in the national building codes, product development and research as well as evaluation of the use of new materials and construction principles.

Key architect and design institutions are the Royal Danish Academy of Fine Arts, School of Architecture. Here the Institute for Building Technologies, as part of the CINARK (Centre of Industrialised Architecture) and the CITA (Centre for IT and Architecture) conduct research on new materials and their performance. At the Aarhus School of Architecture, the key player is the Institute for Architectural Design, which conducts research on materials and construction, while smart materials such as thermochromatic inks are being investigated at the Danish Design School and Designskolen in Kolding.

At present the above-mentioned institutions are only marginally involved in and aware of the potential of nanotechnology for construction, but they represent an important interface to the construction industry in general.

In addition to these institutions, at least two other innovation initiatives are of high interest to NanoByg. One of these is ECTP-Denmark. This is a national Danish offspring of the EU European Construction Technology Platform (ECTP). ECTP-Denmark is an open innovation network consisting of major institutional players as well as large manufacturers of building components. ECTP-Denmark functions currently as the main platform for coordinating and identifying R&D activities in Danish construction. In this innovation network, some research areas that could be relevant to NanoByg have recently been identified but there has hitherto been no explicit focus on nano-activities. A main objective of ECTP is, however, to help the Danish construction industry to take advantage of the R&D resources of the 7th



3XN, Musikhuset, Amsterdam.
Interior. 2005.
Photographer: Adam Mørk



3XN, Musikhuset, Amsterdam.
Interior. 2005.
Photographer: Adam Mørk



3XN, Musikhuset, Amsterdam.
Interior. 2005.
Photographer: Adam Mørk

European Framework, where there is growing interest in nano-construction (see policy chapter).

Another possible partner for NanoByg could be Building Lab DK, which is an innovation initiative launched by the Foundation Realdania (www.realdania.dk). Building Lab DK is particularly focused on innovation in relation to mass-customisation and cross-sectoral ways of working. It is thus an initiative that aims to support innovation by experimenting with new ways of organising the building process and value-chain. Furthermore, Building Lab DK works to improve the coherence between the many initiatives already implemented by construction firms.

Other centres that could be helpful in the NanoByg project could be the Danish Architecture Centre (DAC), which collaborates closely with the Foundation Realdania. This centre is primed for dissemination either through seminars and/or exhibitions. Similarly the Danish Design Centre can provide a network of Danish designers spanning the fields of furniture, textile and industrial design.

A more comprehensive list of relevant construction players, institutions and networks is given in Appendix 2 and 3.

4.1.2 International initiatives for the support of R&D in construction

At the EU level, efforts aiming to develop the construction industry are coordinated by the European Construction Technology Platform (ECTP). A specific nanotechnology trajectory for the construction industry is more clearly envisioned at the European level than at the Danish level (see next chapter on policy).

The strategic priorities of ECTP are carried out by Eureka Build which is a unit under the Eureka Network. This network aims to support business-driven innovation in collaboration between research and industry by generating (FP7) R&D projects.

Another EU network under ECTP which aims to promote R&D in the construction sector is ERABuild. The strategy of this project is to establish an international R&D programme focusing on sustainable development in construction. A short-term goal is the development of a learning network of governmental organisations. In Denmark representatives from EBST (the National Agency for Enterprise and Construction) run the Danish network.

These networks could both be relevant for NanoByg as a means to establish international innovation projects in collaboration with other EU participants.

In addition to the EU initiatives, Nordic collaboration could be of interest to NanoByg. The Nordic Innovation Centre is the Nordic Council of Ministers' single most important instrument for promoting an innovative and knowledge-intensive Nordic business sector and Nordic synergies. The construction sector is identified as a priority business sector. The total project portfolio of the Nordic Innovation Centre consists of approximately 120 ongoing minor innovation projects and



*Henning Larsens Tegnastue.
Reykjavik Koncert og
Kongrescenter.
Rendering: HLT*



*Henning Larsens Tegnastue.
Reykjavik Koncert og
Kongrescenter.
Rendering: HLT*

networks. The Nibcor project aims at facilitating Nordic R&D projects in the construction sector, focusing on themes like user-driven innovation and the digitalisation of the construction sector.

4.2 Actors and institutions in nanotechnology

4.2.1 Danish actors and institutions in nanotechnology

Today, Danish nanoscience mainly takes place in four big nano-centres: iNANO at the University of Aarhus that includes the University of Aalborg, the nano-centre at the South Danish University (SDU), Nano•DTU at the Danish Technical University and the Nano-Science Centre at the University of Copenhagen. These centres are only partly separate units. The latter two have recently made an alliance. There is also considerable nano-research at Risoe National Laboratory. In January 2007 Risoe merged with DTU and the Royal Veterinary and Agricultural University merged with the University of Copenhagen, though this is not expected to lead to any major immediate changes in the organisation of nano-knowledge production. All things considered we are seeing what for Danish conditions is an unusually high degree of centralisation in research activities.

Also the seven GTS institutes are to various degrees active in nanotechnology development (as illustrated in the mapping chapter), in particular dealing with more application-oriented work and with extensive industry contacts.

The Danish nano-centres represent easily identifiable nanoscience environments making it easier to contact and collaborate with the nanoscientists. Each centre has a practical coordinator of some kind. With the exception of Nano•DTU, this is quite a new function still in the process of consolidation.

The creation of the nano-centres has caused increasing attention on nanoscience and nanotechnology in Denmark, not least among companies. All the centres are working on attaching companies in different ways, quite a new effort for many of these traditional research environments that are focused on fundamental research. Traditional industry collaboration is greatest at DTU and Risoe.

While some of the research groups and sub-centres have existed for a while, 10–15 years, the above-mentioned nano-centres (using the nano-term) were established very recently. Also several interdisciplinary “nano-courses” and Ph.D. Schools have been established in recent years.

A national nano-network “NaNet” was established in 2005 with public funding aiming at furthering nano-knowledge exchange and networking, particularly through a portal (www.nanet.nu). NaNet is situated at the Technical University of Denmark and is partly membership-funded. It is a part of the NanoByg pre-project group and is a natural gateway to the nano-community. NaNet also has international links; it shares offices with the Danish-Swedish “Nanoøresund” network and collaborates with “Nanoforum”, the main EU-supported nano-network focusing on dissemination information about nanotechnology.



*PLOT=B.I.G+JDS . Maritimt ungdomshus, 2002, Amager.
Photographer: MADS HILMER*



*PLOT=B.I.G+JDS . Maritimt ungdomshus, 2002, Amager.
Photographer: PAOLO ROSSELLI*



*PLOT=B.I.G+JDS . Maritimt ungdomshus, 2002, Amager.
Photographer: PAOLO ROSSELLI*

4.3 Actors and institutions within nano-construction

4.3.1 Danish actors and institutions within nano-construction

Core nano-construction research focused on cement and windows is going on at the Department of Civil Engineering at the Technical University of Denmark, at the NMR Centre at Aarhus University, and at the Danish Technological Institute. The large cement manufacturer, Aalborg Portland, collaborates through NanoCem with all three actors and has recently entered into collaboration with the iNano Centre. None of the Danish centres or networks focuses solely on nano-construction.

4.3.2 International actors and institutions within nano-construction

The information below on international actors and institutions in nano-construction has been obtained through reports¹⁶, the web and personal contacts.

Nine foreign or international initiatives have been identified who focus on the opportunities that nanotechnologies may bring to the construction sector. These initiatives range from projects to permanent networks and private or public laboratories dedicated specifically to construction research and product development. The initiatives are briefly described in the Table below.

A Nordic innovation project "Green Nanotechnology in Nordic Construction" (2006-2009) supported by the Nordic Innovation Council is just starting. The project will particularly look at firm strategising, policy measures and identifying Nordic strengths and synergies, but will also try to build up a Nordic dissemination platform directed at both companies and scientists.¹⁷

In Appendix 2 and 3, there is a more detailed description of these initiatives. As examples, two permanent networks are described in the box below: NanoCem, a European formal collaboration between industry and academia, and RENAC, Valencian network between research groups working on construction and/or nanoscience.

¹⁶ see Gann, 2003, Bartos et al., 2004, Nanoforum 2006, VDI 2006. A Rilem Technical Committee 197-NCM Nanotechnology in construction materials was established in 2002 with the objective of, among others, to produce State-of-the-art Report and a survey of existing potential applications in construction (Bartos 2004).

¹⁷ Maj Munch Andersen, Måns Molin, both Risoe and Morten Bøgedahl, NaNet, from the NanoByg pre-project group participates in this project with Andersen as project leader.

Name	Country /Region	Thematic focus	Mode of organisation	Ranging area	Goals and main activities
NRC-IRC	Canada	Cement and concrete, bitumen, fire protection, indoor air quality, and insulation	Research centre/governmental agency	National	Product development, exploitation of Intellectual Property Rights
NRC-IRC	Canada	Cement and concrete, bitumen, fire protection, indoor air quality, and insulation	Research centre/governmental agency	National	Product development, exploitation of Intellectual Property Rights
NanoCem	Europe	Cementitious materials	Network	Europe	Fundamental research
NANO COM	Scotland	Construction materials	Research centre/university	National	Fundamental research
NANOC	Spain	Development of various nanomaterials (high performance material, nano/micro structures, modelling materials)	Research centre/private company	International	Exploitation of Intellectual Property Rights
RENAC	Spain	Nanoparticles, nanocomposites, sensors and basic nanotechnology	Network	Valencian Community, Spain	Fundamental research, exchange of resources, commercial exploitation of nanotechnologies
Nano House	Australia	Roof, paint, coating, glass, lighting, energy	Network	International	Demonstration and development of nanotechnologies
Glass House	Australia	Glass	Network	International	Demonstration and development of nanotechnologies
Nano architecture.net	US	Various nano-construction activities and cases	Web portal	US/international	Dissemination towards architects
Green Nano Nordic Con	Denmark, Sweden, Finland	All nano-construction, company cases	Research and dissemination project	Nordic	Innovation research, dissemination towards companies, scientists and policy makers

Table 4.1. Overview - construction sector.

Case: NanoCem (www.nanocem.org)

NanoCem is a European formal partnership funded in 2002 for fundamental research on cementitious materials. It comprises 23 academic and 12 industrial partners and brings together researchers, expertise and equipment to tackle projects aimed at generating knowledge for the development of new materials and the improvement of existing materials.

The network undertakes centrally financed core projects that involve several partners. Furthermore, each academic partner contributes with results from at least one of their independently funded research projects. Through workshops, gaps are identified and new projects are established with funds from the industrial partners. Moreover, other workshops and collaborations are funded by the consortium in order to continue the process of identification of key areas where basic research is needed. Proposals are evaluated by the industrial partners (Industrial Advisory Board) and the academic partners (Scientific Committee) and agreed to in plenum (Assembly).

The role of the Industrial Advisory Board is to define research needs arising from the point of view of industry and to assign priorities. The Scientific Committee agrees on common goals and priorities.

Broadly speaking, research activities within the consortium aim at achieving significant progress with regard to sustainability, usability and multi-functionality. The first is about improving performance and durability and reducing the consumption of natural resources. The second aims at making concrete and other cementitious materials easy to apply and maintain in many different applications. Finally, new functionality may be given to concrete and cementitious materials to serve specific customer needs, such as improved indoor climate, air quality, appearance, or even sensor technology capable of monitoring and maintaining cementitious structures.

Case: RENAC – Valencian Network for Application of Nanotechnology in Construction and Habitat products (<http://www.nano-renac.com/inicio.php>)

RENAC was founded in 2005 with the aim of creating a long-term scientific and technological structure capable of integrating the research efforts in the field of nanotechnology to construction and habitat products. Through integrated efforts they aim at progress towards full exploitation of the commercial, competitive and even societal benefits of nanotechnology.

The network comprises eight technological institutes which research in different traditional materials used for construction, such as wood, plastic, concrete, ceramic, stone and metal. Besides, twelve research groups from three Valencian universities contribute to the network with a recognized excellence in different nanoscience fields as interface science, nanoparticles synthesis, nanocomposites, mesoporous materials, chemical sensors, and polymer science.

Nanoresearch in the network has been divided into four complementary “platforms”: nanoparticles, nanocomposites, sensors & smart systems, and basic nanotechnology. RENAC works with projects, joint collaboration for specific purposes, and exchange of human and material resources. In a new

stage the structure intent to incorporate an industrial group with companies interested in getting improvement of their global competitive position by making proper use of nanotechnology.

In Germany the ministry of research is currently considering establishing a new initiative in nano-construction with collaboration between business and knowledge institutions. They have held three workshops and published a book on the basis of this (VDI 2006), but discussions are still ongoing. The VDI (the German Association of Engineers) is very active in nanotechnology analysis and is responsible for the work. VDI is very interested in a dialogue about a possible NanoByg initiative.



3XN, Liverpool National Museum.
Rendering 3XN.



3XN, Liverpool National Museum.
Rendering 3XN.

5 Policy interests, research and development programmes

This chapter highlights the main international and Danish policy trends, views and initiatives which may influence the development of nanotechnology in construction. Internationally, the main focus is on EU aspects. The chapter is based on a desk study and interviews in Danish ministries. In order to cover policy interests and priorities in relation to both construction and nanotechnology, the chapter reviews in the following order:

1. Policy on innovation in construction
2. STI (Science, Technology and Innovation) policy in relation to nanotechnology
3. Policy on the environment, risks and energy

The discussion, particularly on the latter point, is complicated by the fact that some policy areas are covered by different ministries. E.g. while environmental options and energy issues are closely related, they currently come under two different ministries (respectively the Ministry of Environment and the Ministry of Industry and Economic affairs) in Denmark. Risk issues, a theme of great importance to nanotechnology, is dealt with by both the Ministry of the Environment, the Ministry of Internal Affairs and Health, and the Ministry for Employment.

5.1 Construction policy

5.1.1 EU and general trends

The overall coordination of EU policy for the construction sector is carried out by the European Construction Technology Platform (ECTP). The aim of ECTP is particularly to support better coordination of the research process, at both an industrial and academic level, to remedy the well-recognised problem of fragmentation in the construction sector. Some of the overall objectives of the ECTP which can be related to the potential of nanotechnology include¹⁸:

- Action to reduce the use of energy, materials, and other resources in construction and in the built environment
- The creation of safe and healthy working and living environments for European citizens
- The streamlining of national and European legislation to create a truly common market for construction products and services

These objectives are represented in further detail in 'Vision 2030 for the European construction sector'¹⁹. The strategic goals formulated in this strategy are further

¹⁸ see: <http://www.ectp.org/presentation.asp>

¹⁹ <http://www.ectp.org/documentation/ECTP-Vision2030-25Feb2005.pdf>

outlined in a series of Strategic Research Agendas (SRA)²⁰, consisting of specific roadmaps and strategies. The strategies are to be implemented in detail in specific R&D programmes such as the Seventh Framework Programme, technological development and demonstration activities (2007 to 2013), Eranet and Eureka.

ETCP has formulated 7 focus areas²¹. Under the focus area 'Materials', nanotechnology is emphasised as techniques with the potential of creating a 'breakthrough' within the manufacturing of building materials.

5.1.2 Danish construction policy

The National agency for Enterprise and Construction (NAEC), is an agency under the Ministry of Economic and Business affairs responsible for Danish construction policy.

The agency has been monitoring the development of nanotechnology since at least 1998. Increasing interest in the potentials of nanotechnology can be identified, especially in relation to EU programmes, and efforts are made to form alliances with other Nordic countries in this area. NanoByg may be able to benefit from participation in such alliances.

It is furthermore the intention of the agency to promote the commercialisation of nano-products through work on international standards. Nano-products are identified as a possible strategic area in relation to a long-term energy research programme for construction, and it is assessed that nanotechnology will have a major impact on the development of the construction industry. NAEC is awaiting opportunities in relation to new surfaces and sensor technology and is closely following the potential of nanotechnology for construction

NAEC is also working with the stakeholders of the construction industry, in order to present a common policy plan for focus areas within construction. The list is not yet published, but NAEC has revealed that innovation and competition is focus areas in the policy plan. NanoByg aims to investigate innovation potential and it will be of high interest for NAEC, especially new materials, indoor climate, facility management and intelligent building materials are some of the recurring and important areas of interest

“At large NAEC sees NanoByg as an important initiative for the Danish construction industry because of its dual focus to create innovation and investigate the structural and institutional arrangement of the construction industry that can make the construction sector more prosperous.”

- Jesper Rasmussen, Vice Director, National Agency for Enterprise and Construction, Vice Director

²⁰ http://www.ectp.org/documentation/ECTP-SRA-2005_12_23.pdf

²¹ : Underground Construction, Cities and Buildings, Quality of Life, Materials, Networks, Cultural Heritage, Processes & ICT

5.2 Science, Technology and Innovation (STI) policy and nanotechnology

5.2.1 The EU and general trends

Since the 4th Framework Programme (1994-1998), nanotechnology projects have been increasingly supported by the European Community's funding for research. In the FP7, the EU Member States have proposed a total of EUR 3.500m for funding the nanotech programme ("Nanosciences, nanotechnologies, materials and new production technologies", called NMP).

In the FP7, two Technology Platforms have recently been set up in nanotechnology: nanoelectronics and nanomedicine, i.e. fairly traditional high-tech areas where there is widespread early uptake of nanotechnology. But the construction industry is also identified as a promising area for the application of nanotechnology. The figure below shows FP7 thematic priorities vs. the construction Strategic Research Agenda²² (SRA).

7thFP: Building the Europe of Knowledge/NMP

SRA Coverage by thematic programmes – Detail

FP7 THEMATIC PRIORITIES vs construction SRA (X)= very relevant , x= relevant Part of NMP: 1=nano, 2=mat, 3=prod, 4= integration	1. Health	2. Biotech	3. IST	4. NMP	5. Energy	6. Env	7. Transport	8. Socio	9. Space	10. Security
1 Resource efficient and clean buildings			x	(X)	x	x		x		
2 Technologies for Healthy, Safe, Accessible and Stimulating Indoor Environments				(X)		(X)		(X)		
3 Innovative use of underground space			x	(X)			x			
4 Reduce Environmental and Man-made Impacts of built environment & cities				(X)		(X)				
5 Sustainable Management of Transports and Utilities Networks				(X)			(X)			
6 A living cultural heritage for an attractive Europe				(X)		(X)				
7 Improve Safety and Security within the Construction Sector				(X)				(X)		
8 Industrialisation through integrated processes			x	(X)				x		
9 High added value construction materials			x	(X)				x		
10 Nanotechnologies for materials in construction			x	(X)						
11 Technologies and engineering for innovative added-value services offered by SMEs			x	(X)				x		

CT/DGRTD/G2 21 NOV 2006

Figure 5.1. FP7 thematic priorities vs. construction SRA. Note x: relevant and (x): very relevant. (Tokamanis, 2006)²³

²² http://www.ectp.org/documentation/ECTP-SRA-2005_12_23.pdf

²³ Nanotechnological opportunities to meet the innovation challenges of the construction sector were pointed out by Christio Tokamanis at a meeting on FP7 in Versailles, 21-22 Nov 2006 (Tokamanis 2006), see http://www.ectp.org/documentation/ECTP-SRA-2005_12_23.pdf.

As can be seen from the figure *NMP* is considered very relevant for all the identified construction SRAs.

Among the NMP activities, the most interesting for the construction sector is the activity “*integration of technologies for industrial applications*”²⁴. This research is to enable and sustain the knowledge-based transformation of current industrial sectors and the development of new science-based sectors through the integration of new knowledge from nano-, material, and production technologies in sectoral and cross-sectoral applications.

Construction is clearly among the identified industrial sectors in need of a knowledge-based transformation. In the recent FP7 call, we find one call out of four targeted at nanotech in buildings: “Resource efficient and clean Buildings”, where nanotechnology is linked to environmental improvements in construction²⁵. Furthermore, of the two nano-topics to be implemented via ERANET and ERANET Plus under NMP, one is directed at construction.²⁶

These policy signals are very much in line with overall trends in EU STI policy, as recently expressed in the Aho Report of 2006 (EC 2006). The 3% core target for investment in R&D is combined with a core emphasis on the need to develop innovation-friendly markets; i.e. rather than just strengthening investments in R&D, there is a stronger emphasis on user-driven innovation than hitherto and human resource development as a means of creating an innovative and competitive Europe. Large-scale strategic actions are called for where supply-side measures to raise investment in R&D can be combined with processes to create a demand and a market. So far, seven promising areas are suggested: pharmaceuticals, e-health, security, digital content, transport, energy and the environment. The last four have some implications for construction and civil engineering.

The new STI policy signals are clearly reflected quite strongly in the FP7 nano-policy area, which should open up new opportunities for formulating EU projects in nano-construction. Overall, the new policy trends fit well with the idea of NanoByg.

5.2.2 Danish STI nano policy

²⁴ http://cordis.europa.eu/fp7/cooperation/nanotechnology_en.html

²⁵ NMP-2007-4-5 “Resource efficient and clean Buildings” deadline for applications in May 2007, http://cordis.europa.eu/fp7/cooperation/nanotechnology_en.html.

²⁶ NMP-2007-4-7 “ERANET on Construction: Integration of technologies for industrial applications”, http://cordis.europa.eu/fp7/cooperation/nanotechnology_en.html

The Danish STI policy on nanotechnology has been formulated by the Ministry of Science, Technology and Innovation²⁷. The policy has a national and international focus on the development of nano. On the international level it is mostly concerned with the formulations of FP7 on nanotechnology to secure that the areas where Denmark is strong are taken into consideration. There are currently Danish efforts to try to strengthen the establishment of networks of competent stakeholders (e.g. nanoscientists and companies) around the framework programmes. At the national level the Ministry has issued a programme (NABIIT) under the Danish Council for Strategic Research that among others focuses on nanotechnology and it also diffuses research funds through the established councils and funds in the area of emerging technologies, like the Council for Technology and Innovation and the High Technology Fund.

The overall Danish STI policy has been recently formulated in the globalisation strategy of 2006 (VTU 2006). The strategy aims to turn Denmark into a leading growth, knowledge and entrepreneur society by strengthening education, research and innovation. An important part of this strategy is greater emphasis on the promotion of high technology, including nanotechnology. There is no real national nano-strategy in Denmark, but a Danish nanotechnology forecast came up with the first recommendations and suggestions for an action plan in 2004 (VTU 2004). Target areas then were more general nanoscience areas with little emphasis on industrial application; the only application area defined was nanomedicine whereas construction was not mentioned²⁸.

Following the increasing policy interest in high-tech, R&D nano-dedicated funding has started in Denmark, though in international terms, the relative amount of Danish funding going into nanotechnology is not very high (Andersen, 2006b). Two important Danish institutions for STI funding are The Danish Council for Strategic Research and Danish National Advanced Technology Foundation. The Strategic Research Council directs funding at the general purpose technologies: nanotechnology, ICT and biotechnology through the The Programme Commission on Nanoscience, Biotechnology and IT (NABIIT)²⁹. However, funding has mainly been allocated to basic research, whereas more engineering type applications have been very few so far.³⁰

The High Technology Foundation also supports research and innovation in nanotechnology, biotechnology and ICT targeted at single projects. These initiatives have to be based on public-private collaboration. The majority of the approx. EUR 30m allocated this year has been directed to large high technological initiatives, while a smaller proportion of the funds has been directed to initiatives for small and medium-sized companies. The foundation finances up to 50% of the expenses of the selected initiatives. Two projects related to the development of

²⁷ The statements in the following section are based on an interview with David Budtz Pedersen, Joachim Quistorff-Refn and Niels Hovgaard Steffensen, Ministry of Science, Technology and Innovation, December 19, 2006.

²⁸ The Danish Concrete Council made a comment to the report noting that nanoconcrete did not receive the attention it deserved.

²⁹ "NABIIT", forskningsstyrelsen, www.fist.dk.

³⁰ According to Lars Lading, head of the Strategic Research Council on Technology and Production, at the NanoByg workshop January 22, 2007.

new building materials have recently received funding, one of which is concerned with the application of nanotechnology in cement, the most well-established nano-construction theme.³¹

An exception to the science-oriented STI policy is a minor funding given to the creation of NaNet in 2005, the Danish national nanotech network supported by the Danish Council of Technology and Innovation, which seeks to promote knowledge exchange and networking between nano-interested actors nationally (see more about NaNet in the positioning chapter).

The Danish Ministry of Science, Technology and Innovation has expressed considerable interest in the NanoByg idea. They do not generally support single sectors or areas, but the idea of promoting a stronger innovation perspective and focusing more on the application and industrial uptake of nanotechnology they see as interesting. NanoByg could be an interesting first example of this approach. They are very positive towards bottom-up activities such as NanoByg, where actors themselves show initiative and interest. NanoByg could provide a platform that could enable a better/new dialogue between STI nano-policies and the construction sector, particularly in connection with gaining input for the Danish research councils and to FP7 in the future.

Concrete initiatives referred to by the Ministry which could support or supplement NanoByg include the “innovation consortia” supported by the Technology and Innovation Council. It entails a form of innovation partnership between researchers and companies. The innovation consortia will gain considerably more funding in the coming years according to the new Danish innovation action plan. Another option is to establish a technological service institute focusing on nano-construction; such an initiative has been considered but not yet accepted because there are concerns that industry is not ready for this yet.

A possible barrier to the NanoByg idea is that the STI system in Denmark leaves limited opportunities for interdisciplinary research and development. Initiatives such as NanoByg involving a great variety in the type of actors (including both high and low-tech industrial actors, non-industrial companies such as architects and designers, engineers, natural scientists and social scientists) and activities are unlikely to get funding through traditional research channels. Even for innovation initiatives (such as innovation consortia) it would be unusual.

³¹ Core actors in the project is the large cement company Aalborg Portland and the iNANO centre, see case 1.1.

5.3 Policy on the environment, risks and energy

5.3.1 International policy on the environment, risks and energy

In recent years environmental policy has seen a shift away from pure regulation towards a broader innovation perspective for reaching sustainability goals; i.e. there is more emphasis on furthering technological change for increased energy and eco-efficiency (WBCSD 2000, Kemp and Andersen, 2004; Kemp, Andersen and Butter, 2004). At the EU level, environmental and innovation policies are increasingly linked via the European Environmental Technologies Action Plan (ETAP) (COM (2004) 38). New policy signals are sent in the simultaneous pursuit of environmental and competitiveness goals (Kemp and Andersen, 2004; Kemp, Andersen and Butter, 2004). "Eco-innovation" is beginning to be integrated more systematically in innovation policy, noticeably at the EU level, (see COM 2006). 32

Climate change issues are more than ever becoming topical, gaining increased international concern and increasingly being connected with energy policies. This trend is strengthened by the close linkage between defence and energy policy related to the increasing interest of western powers in becoming less dependent on the Arabian and Russian fossil fuel supply. Even environmentally low-profile governments like the US are introducing new strategies. Since the construction sector is a key energy consumer (between 40–70% of all energy consumption in most countries) and a major contributor to waste production, the construction sector is key target for environmental and energy efficiency policies.

The interesting thing is that eco-innovation is very much a global concern and not least Asian countries are strongly on the move³³. China, the fastest growing economy in the world and a rising nanotech nation, is finally taking environmental concerns seriously in their new 5-year action plan. The plan includes the first Chinese energy efficiency standards in urban construction, which could influence the world construction market considerably.

32 Compare more specifically the upcoming FP7 programme, the likewise upcoming Competition and Innovation Programme (CIP) and the new Innova programme for sectoral innovation policy that all include targeted action for eco-innovation.

33 Dramatic recent policy strategies and measures in this area are:

Asia: "Green growth" strategy of UNESCAP

Japan: Specific resource efficiency goals are formulated.

China: a "circular economy" strategy with strong emphasis on sustainability (5-year plan 2006–2010). Plans to invest USD 175,000m in environmental protection,

includes the first Chinese energy efficiency standards in urban construction.

US: Sustainable energy production and energy efficiency as core targets

EU: "Clean, clever and competitive" as core vision (Lisbon process)

Internationally, the primary policy concern in relation to nanotechnology is the risks related to health, the environment, and labour conditions (European Commission 2004), while the positive side has received little attention. Hitherto (science-fiction-like) speculation about risks has been widespread while actual research results are only beginning to emerge around the globe. The results so far conclude that risk issues vary considerably in the broad nanotechnology field and that the core concern is related to free nanoparticles where more research is needed (Colvin 2002, Arnall, 2003, European Commission 2004, Royal Society 2004, ECT group 2003). See also appendix 4 on risk issues.

In the international standardisation, work risk issues (for both labour, health and the external environment) receive considerable attention and both CEN and ISO are working intensely on this. Results are not expected until in a year or two, possibly later. Also more general work on nano-definitions and metrology is being carried out here. Danish Standard has created a Danish support group (Dansk Nanoteknologisk Forum) with a range of different actors to follow this work.³⁴

The EU nano-action plan emphasises the need to develop an effective, responsible, and sustainable nano-strategy. The new FP7 nano-programme interestingly puts new emphasis on eco-opportunities from nanotechnology, including construction, as highlighted in the nano-policy section above.³⁵

5.3.2 Danish policies

Danish policy on the environment and risk³⁶

After some years of low-priority, environmental policy is now again receiving increasing attention in Denmark, not least in connection with energy self-sufficiency concerns. While environmental regulation has been a main concern, the Ministry is about to launch a new environmental technology action plan, expected in February 2007. DKK 144m has been targeted at promoting eco-innovation. Altogether, the funds will be directed at small rather than big initiatives. Some of the new measures expected are funds for demonstration initiatives. It is also expected that general-purpose technologies, including nanotech, will be highlighted as a possible means of enabling new eco-innovation.

In the Danish EPA, there is generally a strong interest in measures aimed at the construction sector, due to the high environmental impact of the sector. At the Ministry, they express a considerable interest in the NanoByg idea, though at the moment no concrete initiatives can be pointed to. One possibility is to establish a “partnership” for nano-related eco-innovation in construction. “Partnerships for

34 E.g. the company Fibertex, material supplier to the construction industry, participates here and so do NaNet, Maj Munch Andersen and Måns Molin, Risoe from the NanoByg pre-project group.

35 http://cordis.europa.eu/fp7/cooperation/nanotechnology_en.html, see NMP-2007-4-5 “Resource efficient and clean Buildings”.

36 The statements in the following section are based on an interview with Niels Henrik Mortensen, the strategy division of the Danish EPA, 19th of December 2006.



*B.I.G. MTH – Boliger, under construction, Ørestaden.
Rendering: B.I.G.*



*B.I.G. MTH – Boliger, under construction, Ørestaden.
Rendering: B.I.G.*



*B.I.G. MTH – Boliger, under construction, Ørestaden.
Photographer: Ulrik Jantzen*

environmental technologies” is a new initiative entailing a kind of innovation consortia where companies and scientists gain funding for collaboration on eco-innovation in a specific area for a limited time period. In the summer of 2006, five such partnerships were launched, none related to construction. It is currently uncertain when a new round of partnerships is going to be considered.

In recent years, the Danish Ministry for the Environment has taken an interest in nanotechnology, trying to clarify the possible environmental implications of this emerging technology. In 2004–2005, they initiated a Green Technological forecast on nanotechnology, biotechnology and ICT, looking into both risks and opportunities (Miljøstyrelsen, 2006, Andersen and Rasmussen 2006). The forecast concluded that environmental issues, while highly debated, were little integrated in Danish nanoscience and development work and, as a result, considerable nanotechnological eco-opportunities were neglected and risk issues ignored. Construction issues were not particularly highlighted, but some eco-opportunities identified, e.g. nano-coated windows, LED lamps, insulation).

Risk issues are currently the main environmental policy concern, though there seems to be a possible shift in focus towards the opportunities in the upcoming technology action plan. There are currently two Danish cross-ministerial committees on nanotechnology, focusing on the health and risk issues of nanotechnology. One is situated in the Ministry of Health and Internal Affairs, which will be coming out with a statement this spring, the other in the Ministry for the Environment, and has no time limits. These committees illustrate the recent increase in policy interest about the risk aspects of nanotechnology and the need to build up expertise and new initiatives in the field. Also the Danish Ministry of Employment are working seriously with nanorisks issues, see the appendix on risks.³⁷

Danish energy policy and construction

The policy on energy in housing has been formally formulated by the Ministry of Transport and Energy. However, some coordination is taking place between the Ministry of Transport and Energy and the Ministry of Economic and Business Affairs, since this ministry is responsible for the actual regulations related to housing and construction.

With regard to energy in housing, no explicit strategy has been formulated on nanotechnology or nano-materials. This may be a consequence of the regulatory approach. From the oil crises of the 1970s until the late 80s, energy efficient housing was subsidised through various development programmes. These programmes were shut down in the 90s. Since then the focus of the manufacturing industry on energy efficient materials has been declining.

Today the dominating policy instrument in relation to energy efficient housing is the standards on the maximum energy consumption formulated in the building regulations. These were recently tightened significantly.

³⁷ Also Teknologirådet (The Danish Technological Council mediating issues on technology towards the wider public) came up recently with a report on regulation needs related to nanotechnology (Teknologirådet, 2006)

There are otherwise few policy initiatives in relation to innovation and product development in energy efficient materials. Such developments are supported through the Energy Research Programme (Energiforskningsprogrammet).

The Danish government has just launched a new and very ambitious energy plan in January 2007 to diminish Danish dependency on fossil fuels. Investments will double so that DKK 1,000m. will be spent annually after 2010 in this area. Emphasis is placed on both the promotion of renewable energy technology and improved energy efficiency. Interestingly, low energy buildings are pointed out as one out of four Danish strengths to be prioritised in the future.

5.4 Policy conclusions

This chapter has highlighted the many policy trends, both in construction, transport, STI, the environment, risks and energy which potentially support initiatives such as NanoByg both in Denmark and internationally. There is increasing focus on science-based innovation in construction, there is increasing interest in the wider industrial uptake of nanotechnology, including specifically in construction, and there is a very strong interest in the potential energy and environmental gains that nano-construction may offer. Nano-risk issues are given the serious concern they deserve.

An overall policy conclusion is, however, that in relation to innovation in construction, much more focus is given to nanotechnology at the EU level than on the national level. However, as Danish policy increasingly follows European trends it is likely that nanoconstruction, as well as the application of nanotechnology in other low- and medium-tech industrial sectors, will be given a higher priority on the national policy agenda in the future. The question is if Danish actors, none the least the construction industry, are ready to take advantage of the new EU opportunities for engaging in nanoconstruction research and development projects. The mapping exercise in chapter three indicates that they are not and that there is a need for further action at the Danish level. In the next chapter we shall discuss what kind of Danish initiative may be needed.

6 Suggestions for a NanoByg Initiative

This chapter seeks shortly to outline and discuss different suggestions for a possible Danish initiative to promote the application of nanotechnology in construction, the NanoByg idea.

6.1 The challenge of NanoByg

This chapter wants to open up a discussion rather than conclude on an initiative for the relation between nano research and construction industry; however, there are some features that the report means that we can conclude on. The aim of NanoByg is to invoke engagement and initiative in an industry that struggles with structural barriers that hinders prosperous co-operation and learning. If we want to transform and overcome these hinders it is important that the people who experience these barriers in their daily activities are engaged and given voice to such an initiative. Innovation cannot be forced upon a firm or industry; rather, it feeds on the learning process and problems that the industry encounters in their daily activities. Hence, if we aim to generate innovation in the construction industry, the construction industry has to be those that define the problems and bring by the learning.

Also important when we are concerned with technological innovation is that the identification of possible innovation and the innovation process upholds a dialogue between the user of technology (the construction industry) and the developer of technology (the nano community). This both makes the innovation process more effective and efficient in that it secures a limits the risk to market success at the same time as it reaches the market faster. To get this dialogue going is also important for the long term, since it carries potential co-operation and future development possibilities.

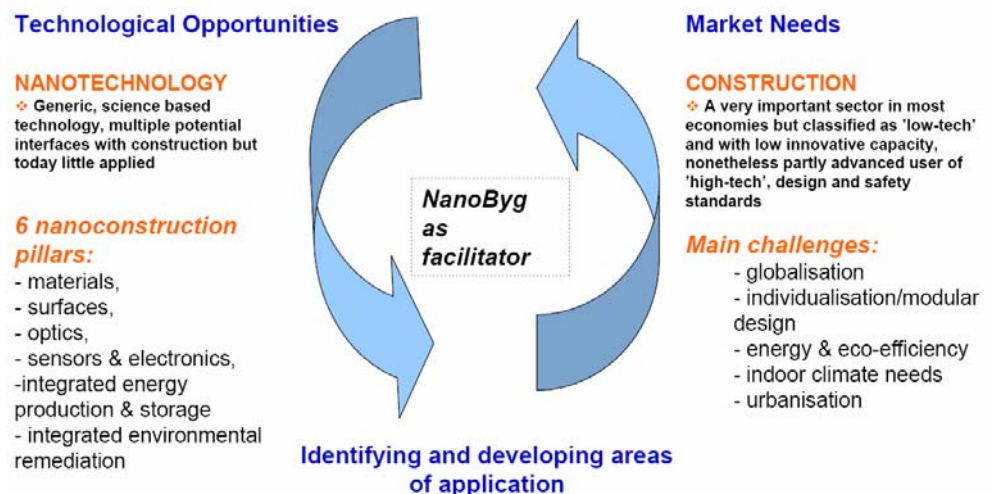


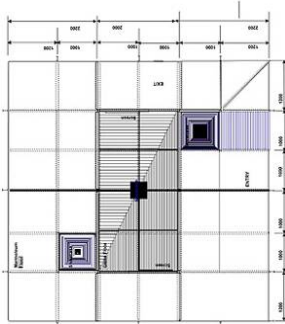
Figure 6.1. The NanoByg idea.



The core task a possible NanoByg initiative should address may be formulated like this:

How do we create innovation in the intersection between the needs of the construction sector and the emerging nanotechnological opportunities?

The NanoByg challenge is considerable. It is no easy thing to apply the high tech, ambiguous and very diverse nanotechnological field in the relatively low tech and fragmented construction sector. In this report we have seen that the uptake of nanotechnology in Danish construction is not very far. Further more that there are major knowledge gaps both on the side of the nanocommunity and the construction community on each others needs and competencies.



Through this report we have seen how the construction industry struggles with structural problems that hinder cooperation and innovation. The fragmented value chain in construction means that the problem definition takes place by an orchestration of a range of actors - material and component manufacturers, contractors, architects, consultants, clients and clients' representatives. These constellations work fairly well, because a well established craft system. However, innovation will introduce new knowledge which means that the actors have to renegotiate their well established practices of the craft system. For an innovation to gain momentum a NanoByg has to provide a space for this negotiation to take place and show examples how these new constellations can work, so that a new technological paradigm can form new practices. Because of this it is important for NanoByg to be creative also on the institutional level and work with different system integrators in the specific innovation context.



*The Glass House, Sydney, Australia, 2003.
Dr Carl Masens, Institute for Nanoscale Technology, University of Technology Sydney 2003 (UTS). Architect James Muir. In collaboration with CSIRO, Haico Schepers, Arups in London, Pilkington Active Glas.*

Fundamentally, though, many actors on both sides show an interest into nanoconstruction, particularly following more in-depth dialogues on the subject. The construction sector may be generally conservative and reluctant towards new technologies, but clearly there are actors, none the least the architects, who are quite proactive change agents and who could come to play a positive visionary role towards nanotechnology development in construction. Such visionary actors with power are absent in most other sectors, meaning that the potential for nanoindustrial uptake may actually be larger within construction than often considered.

Our analysis has shown that there are hesitations on the hype and concerns on the possible risks that need to be taken seriously and weighted with the possible advantages. The still highly open and ambiguous character of nanotechnology carries an uncertainty with it that demands of NanoByg initiative to take a critical approach to nanotechnology. Specifically, it is important for such an initiative to focus on creating a better understanding of how the emergence of nanotechnology may affect the construction sector positively and negatively. For that reason, the NanoByg initiative as suggested entails both a social scientific and natural scientific part, where the social scientific part contributes with more analytical and critical analyses on the commercial trends and effects of nanotechnology in construction, on industry as well as the build environment, generally as well as related to specific technological solutions. The social scientific part is also vital for identifying core

NanoByg



KHR, Jens Bangs
Gæstebolig.
Photographer: Ib Sørensen



KHR, Jens Bangs
Gæstebolig.
Photographer: Ib Sørensen



Henning Larsens
Tegnestue. Woodland
boliger, Sverige.
Visualized by HLT

change actors as well as barriers for nanoinnovation, none the least pointing to how the behaviour of various (constellations of) actors may be shifted.

NanoByg could be seen as a means generally to experiment with and increase the cooperation between construction and research to further a transformation towards a more knowledge intensive industry. The curiosity about nanotechnology (the hype) could be used as a positive lever for advancing more radical and systemic innovation in construction.

6.2 A way ahead

In the following sections we will have a closer look at specific suggestions for a NanoByg initiative. We will go through the following four parameters:

1. The NanoByg purpose/idea
2. The NanoByg focus
3. The methods/activities of NanoByg
4. The NanoByg organisation and position

The first two points we consider fairly general for a NanoByg initiative, whereas the differences in the suggested models mainly lie in the activities and the organisation. Finally 4 different models will be suggested.

6.2.1 The purpose of NanoByg

The purpose of NanoByg is to invoke a productive dialogue between the construction industry and the promising advances in nanotechnology to create innovation.

The uniqueness of NanoByg rests on a combination of:

- Nano research and development targeted to the scale and requirements of the construction industry.
- Collaboration with partners specialised in solving the barriers to technology adaptation in the construction industry.
- A focus on systemic innovations in the construction industry and new problem identification related to nanoconstruction.

Furthermore, it is the vision of NanoByg:

- to turn nanoconstruction into a competitive advantage for Danish construction.

NanoByg



*Dorthe Mandrup Arkitekter.
Jægersborg Vandtårn, 2006.
Photographer: Jens Markus
Lindhe*



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Jægersborg Vandtårn, 2006.
Photographer: Jens Markus
Lindhe*



*Dorthe Mandrup Arkitekter.
Jægersborg Vandtårn, 2006.
Photographer: Jens Markus
Lindhe*

- to use nanoconstruction as a means to develop novel solutions that improve the living conditions in the built environment.
- to harvest the energy and eco-efficiency potentials of nanoinnovation in construction.
- to aim for a responsible and safe nanotechnological development in construction.

Behind the idea of NanoByg lie three assumptions:

- The enabling character of nanotechnology means that it has the potential to create radical and systemic innovations within architecture and construction.
- The present (Danish) nanoscience is to a large extent oriented at application in other industries than construction - hence it is currently unlikely to have a significant impact on the construction industry.
- The fragmented construction sector is likely to have a low uptake and spread of new advanced technologies such as nanotechnology unless careful action is taken.

6.2.2 The focus of NanoByg

NanoByg is as a start anticipated as covering a broad scope both when it comes to construction and nanoareas as well as regional scope and phases. Naturally it is possible to delimit the scope of NanoByg further and focus on specific nano- or construction areas as some of the international nanoconstruction initiatives do (see chapter 5). But if NanoByg is generally to highlight the potentialities of nanotechnology in construction it is necessary to take on such a broad perspective. Furthermore the wide scope opens up for wider systemic innovations across the different nanotech areas.

Construction areas:	6 nano pillars:
<ul style="list-style-type: none"> ▪ buildings ▪ civil works ▪ thematic areas – e.g. indoor climate, moisture, and material strength and durability. 	<ul style="list-style-type: none"> ▪ materials, ▪ surfaces, ▪ optics, ▪ sensors & electronics, ▪ integrated energy production ▪ integrated environmental remediation
Phases:	Regional scope:
<ul style="list-style-type: none"> ▪ pre-commercial and commercial R&D ▪ design, production-, user- and disposal phase ▪ identifying identifying and working with system integrators ▪ institutional institutional analysis and transformation 	<ul style="list-style-type: none"> ▪ national initiative with international linkages



Dr Carl Masens, Institute for Nanoscale Technology, University of technology Sydney (UTS). Architect James MuirIn collaboration with CSIRO and Arups in London.

6.2.3 The NanoByg activities and methods

NanoByg is anticipated to be combining a variety of activities such as:

NanoByg-Tech:	NanoByg-Soc:
<ol style="list-style-type: none"> 1. Knowledge brokering & matchmaking (linking needs and opportunities for problem identification and forming partnerships) 2. Research and development (pre-commercial and commercial) 3. Demonstration 4. Knowledge pooling & dissemination 5. Education 	<ol style="list-style-type: none"> 1. Innovation analyses (how to shift things/actors, identify commercial opportunities, policy and strategy recommendations) 2. Institutional analysis and transformation 3. Technology foresights (visioning) 4. Risk and environmental assessments
Commercialising nanotechnology in construction	

However, the mix and weighting of the different activities may vary in the different organisation models suggested in the following. A special feature is the suggested “knowledge brokering” and matchmaking activities. This activity is key in the NanoByg idea to enhance the dialogue and learning between nano actors and construction actors. It should include professional actors such as the technology transfer offices of various research institutes.

The core idea of NanoByg is to create a platform for arranging a cluster of activities that evolve over time. A NanoByg has to think in temporal terms since its success build on the transformation of attitudes and institutions and identification of system integrators and key players.

A possibility is to think of NanoByg as going through a set of phases where different types of activities dominate at different times (see fig 6.2.). Different project with different focus activities (institutionalization, knowledge mapping and R&D) will go through the different phases where the projects interact with different players in the construction industry and the nano-community. These activities will result in a transformation of the construction industry and its relation to research communities. The project will conclude with strategy and policy recommendation for this dialogical based, innovation driven transformation. Such activities usually result in academic publishing for the participants of natural and social science, but because of the practical focus we can also expect some of the R&D project to be of interest for venturing (internal as well as external).

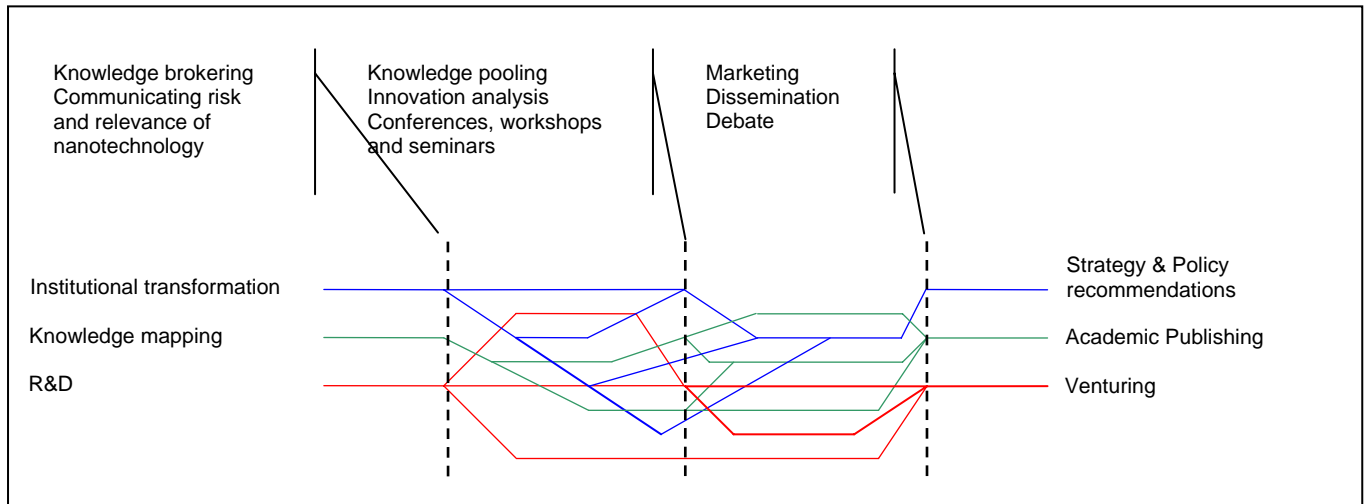


Figure 6.2. The phases of NanoByg

6.2.4 The organisation of NanoByg

The specific organisation of a NanoByg initiative has a major influence on the nature of its impacts and who it reaches.

The organisation of NanoByg depends on the three parameters we have already discussed:

- The purpose
- The focus
- The activities

But also more specifically:

- The financing of (R&D) activities
- The physical setting
- The interplay with the surroundings (openness, network competencies).

If we take here the overall purpose and focus of NanoByg for broadly given as outlined above, the other parameters lead to the following four models for NanoByg:

Scenario	NanoByg Observatory	NanoByg Forum	NanoByg Alliance	NanoByg Innovation Centre
Motto	Highlighting nanoinnovation	Spreading nanoinnovation	Innovation through dialogue and cooperation	Promoting user driven nanoinnovation
Description	The observatory pools, investigates and disseminates information about nanoconstruction to create interest.	The forum mainly coordinates activities among its network members. It is characterized by loose connections.	All parts benefit. Focus on mobilising actors in new innovation constellations.	The innovation centre focuses on creating a strong knowledge base
Main activities	<ul style="list-style-type: none"> -Knowledge pooling -Dissemination -Debate and recommendations (reports, assessments), seminars) - Extensive demonstration activities (one or two Danish NanoHouses) 	<ul style="list-style-type: none"> Knowledge brokering (workshops..) -Dissemination (newsletters) - Funding activities (National, Nordic and EU projects) 	<ul style="list-style-type: none"> Extensive knowledge brokering (workshops, education) - Extensive demonstration (one or two Danish nanohouses) - Funding activities (National, Nordic and EU projects) 	<ul style="list-style-type: none"> - Knowledge brokering - Extensive R&D - Demonstration - Conferences - Extensive Funding activities (National, Nordic and EU projects, venturing) - Marketing Danish expertise
Financing R&D	Minor R&D projects for demonstration purposes	-R&D is mainly financed by the participants.	Own funding of many mainly smaller projects that end with a proof of concept, feasibility studies or demonstration activities..	Own funding of large and small R&D projects
Settings	Centre without walls	Network	Small centre or centre without walls but key nodes in different knowledge institutions	Small centre with walls but mainly virtual
Relations to surroundings	Seeking to create wider public and policy interest in nanoconstruction	Focus on creating a strong national network of scientists and companies	<ul style="list-style-type: none"> - Business network - Creating international linkages 	<ul style="list-style-type: none"> -Business network - Creating international linkages

Table 6.1. Four sketches of a future NanoByg initiative.

Naturally the sketched models may be combined in a different way than outlined here.

Overall, all four models in various ways seek to find efficient ways to promote nanoinnovation in the intersection between nanotechnology and construction, as illustrated by the figure above.

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